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No. 413944

*Final Report*

**INVESTIGATION OF THE OPERATIONAL USE OF CLOUD PHOTOGRAPHS  
FROM WEATHER SATELLITES IN THE NORTH PACIFIC**

*Prepared for:*

METEOROLOGICAL SATELLITE LABORATORY  
U.S. WEATHER BUREAU  
WASHINGTON, D.C.

CONTRACT Cwb 10238

By: Sidney M. Serebreny Eldon J. Wiegman Rex G. Hadfield

STANFORD RESEARCH INSTITUTE

MENLO PARK

SRI

NO. 075

STANFORD RESEARCH INSTITUTE

Menlo Park, California

November 1962

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SRI Project No. 3858

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**Errata Sheet for  
Final Report Contract Cwb-10238 - S.R.I.**

**Page 15, line 22: "(from E to P)" should read "(from E to D)"**

**Page 64, line 17: "(Fig. 31)" should read "(Fig. 30d)"**

**Page 81, 3rd line from bottom: "[Figs. 31(c) and 31(d)]"  
should read - "[Figs. 30(c) and 30(d)]".**

## ABSTRACT

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The operational use of satellite cloud photographs is investigated through a series of TIROS I photographs taken on 21 orbits in the North Pacific from 18 through 24 May 1960. During this period, a sequence of vortices and fronts was observed in the Northern Pacific. Late in the period, blocking action developed in the East Central Pacific. The manner in which these circulation phenomena are reflected in the satellite photographs is discussed.

Positioning of jet streams over the Northern Pacific in relation to the cloud systems is discussed and illustrated for each of the days in the case history.

Atmospheric motions implied by the cloud cover in satellite photographs are studied by means of time sections at a single station (Ocean Station Vessel Papa, 50°N, 145°W). These time sections include computed vertical motions, temperature-dew-point differences, winds and radiosondes, surface cloud observations, along with pertinent satellite cloud photographs. In addition, these time sections are compared to a study made in the North Atlantic of a similar synoptic situation prior to the advent of TIROS I. Comparisons are also made with distributions of atmospheric moisture taken in various synoptic situations by other authors.

Results of the study indicate that satellite cloud photographs are operationally useful. Characteristic cloud patterns accompany frontal air-mass changes. During the first part of the period the cloud distribution closely parallels a model advanced by Bergeron (1951).<sup>\*</sup> Satellite cloud photographs can also be used as an aid in jet-stream analysis.

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<sup>\*</sup>References are listed at the end of the report.

Comparison with other studies indicates that the distributions of certain parameters of atmospheric motion are similar in comparable synoptic situations. Additional studies of the distribution of cloud cover under these circumstances using satellite photographs needs to be investigated. Some features in the cloud photographs that are appropriate for operational use are given.



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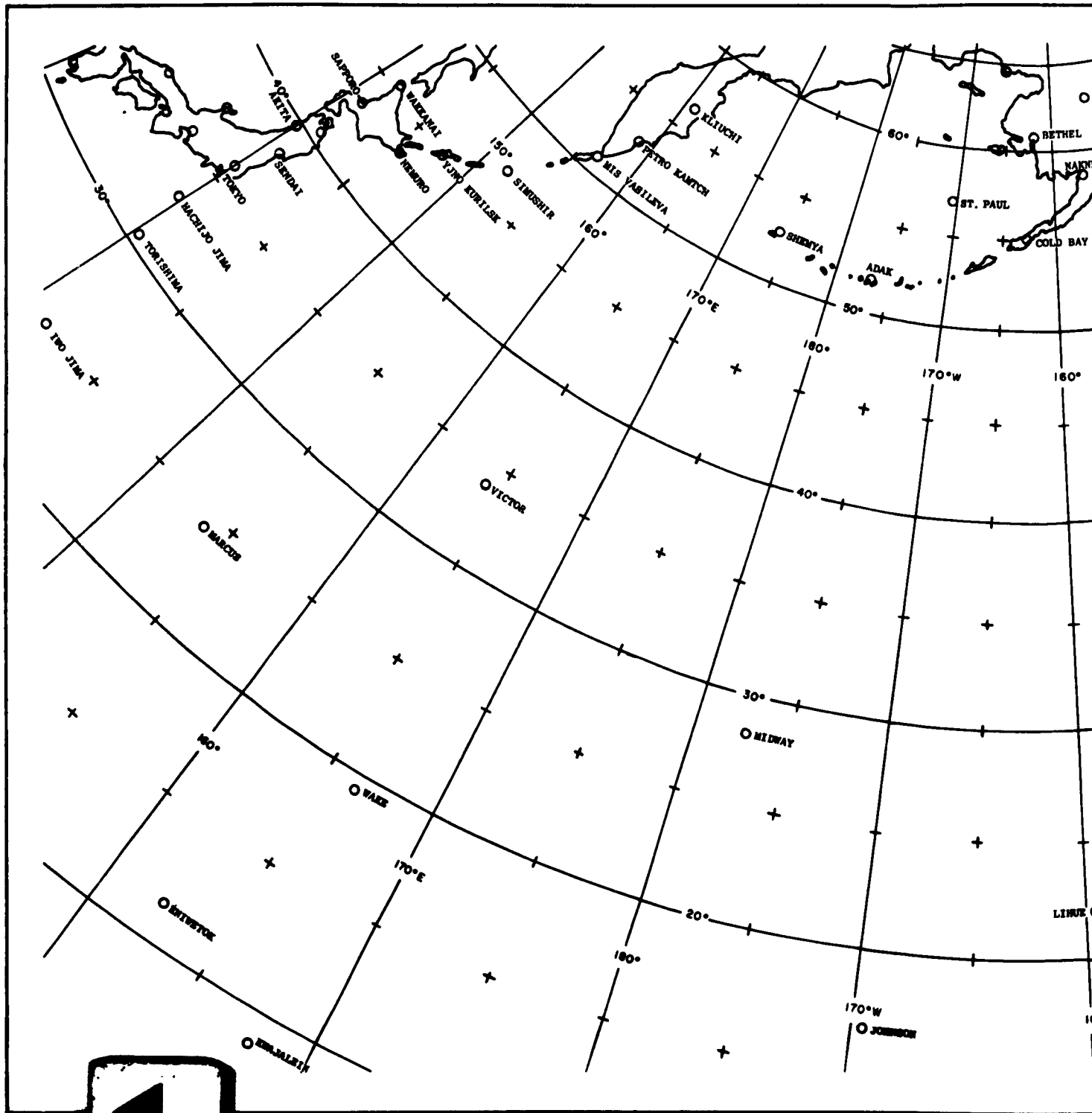
TABLE

Table I	Times of Satellite Photographs . . . . .	1
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## ACKNOWLEDGMENTS

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The authors wish to extend their appreciation to the following people at the Stanford Research Institute: Roland Nagle (Research Meteorologist), for his assistance in photograph location and interpretation; William Viezee (Research Meteorologist), for computation of vertical motions used in Part II; Joyce Kealoha (Meteorologist), for her efforts in gridding and rectification of the TIROS I photographs; Arlyne Burris (Statistical Assistant), for her assistance in the drafting of the illustrations, and Dr. Myron G.H. Ligda, Manager of the Aerophysics Laboratory, for his continued interest and support.



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## I INTRODUCTION

### A. General

There is little question that satellite cloud photography adds a new dimension to the field of meteorology. How meaningful these data will be to a forecaster in the field will depend on his ability to integrate them into his current knowledge of atmospheric parameters, plus the degree to which they enable him to make some statement regarding future conditions. In areas of adequate data networks, certain parameters in the atmosphere already can be fairly well delineated (at least on a large scale), and the cloud patterns are additional and highly desirable data. In areas of sparse data networks the cloud patterns from satellite observations provide the only "complete" atmospheric data available, and it would be highly advantageous if other meteorological parameters could be inferred from these cloud observations.

One of the most interesting and complete sets of photographs in the TIROS I catalogue for the Pacific was obtained during the period 18 May through 24 May 1960. During this time the general pressure pattern changed from a predominantly zonal flow on the 18th of May to a strongly meridional flow by the 22nd, which culminated in a high-latitude "block" (closed anti-cyclonic circulation) on the 23rd, with the westerlies breaking through south of the blocking circulation on the 24th.

Having a case history that included a blocking situation was most fortunate since blocking conditions occur frequently, both in the Atlantic and Pacific, though geographical location varies greatly (Serebreny, Wiegman, and Hadfield, 1957-1958). For example, when such conditions prevail in the Pacific, the blocking anti-cyclone might occur anywhere over an area extending eastward from the Bering Straits to the Yukon, and from the Canadian border northward to the Arctic Ocean. In the Atlantic area the individual high-latitude anti-cyclone may occur anywhere in the area between Norway and the eastern periphery of Greenland, and between the southern coast of England and the Arctic Circle. Consequently, if a unique evolution of the cloud system during blocking situations is determined it will have wide geographical application.

Section II of the report presents a study of the large-scale cloud distributions as seen by a satellite, and their patterned association with the major circulation systems, including the jet stream. Section III shows the association of atmospheric motions with certain changes in the cloud field, in terms of data presented in a time section at a single station (OSV Papa at 50°N, 145°W).

Naturally, many of the conclusions presented in this report must be considered tentative since they are based on only a single case. The hope is, of course, that eventually relationships may be established that show the manner and degree to which atmospheric parameters may be inferred from the cloud photographs.

#### B. Data

During the period of study, analyses were made of 21 orbits of TIROS I which transited the Pacific during the daylight hours. Photographs from the wide-angle camera were generally of high quality and gave a remarkable day-to-day coverage of the Pacific Ocean area. The individual orbit locations are shown in Fig. 1. Note the widespread and almost identical daily coverage afforded by the individual and daily transits. By grouping the orbits to fit the closest 0000 GMT synoptic observations, it was possible to keep all the photographs in the mosaic within 4-1/2 hours of the synoptic reports. The actual picture times of the individual orbits utilized are listed in Table I below.

Rectifications for each orbit were transferred to a Polar Stereographic Projection to facilitate comparison with synoptic analyses drawn to this projection. Pictures were rectified according to procedures outlined by Hubert, 1961. Accurate positioning of rectified cloud patterns was accomplished by reference to landmarks which were visible somewhere in each sequence of pictures. It is estimated that location errors of features shown in this report are usually less than 50 miles.

Photographic mosaics were constructed for each orbit by matching cloud elements on successive frames and by fitting the pictures together in such a manner as to provide a reasonable spatial relationship when



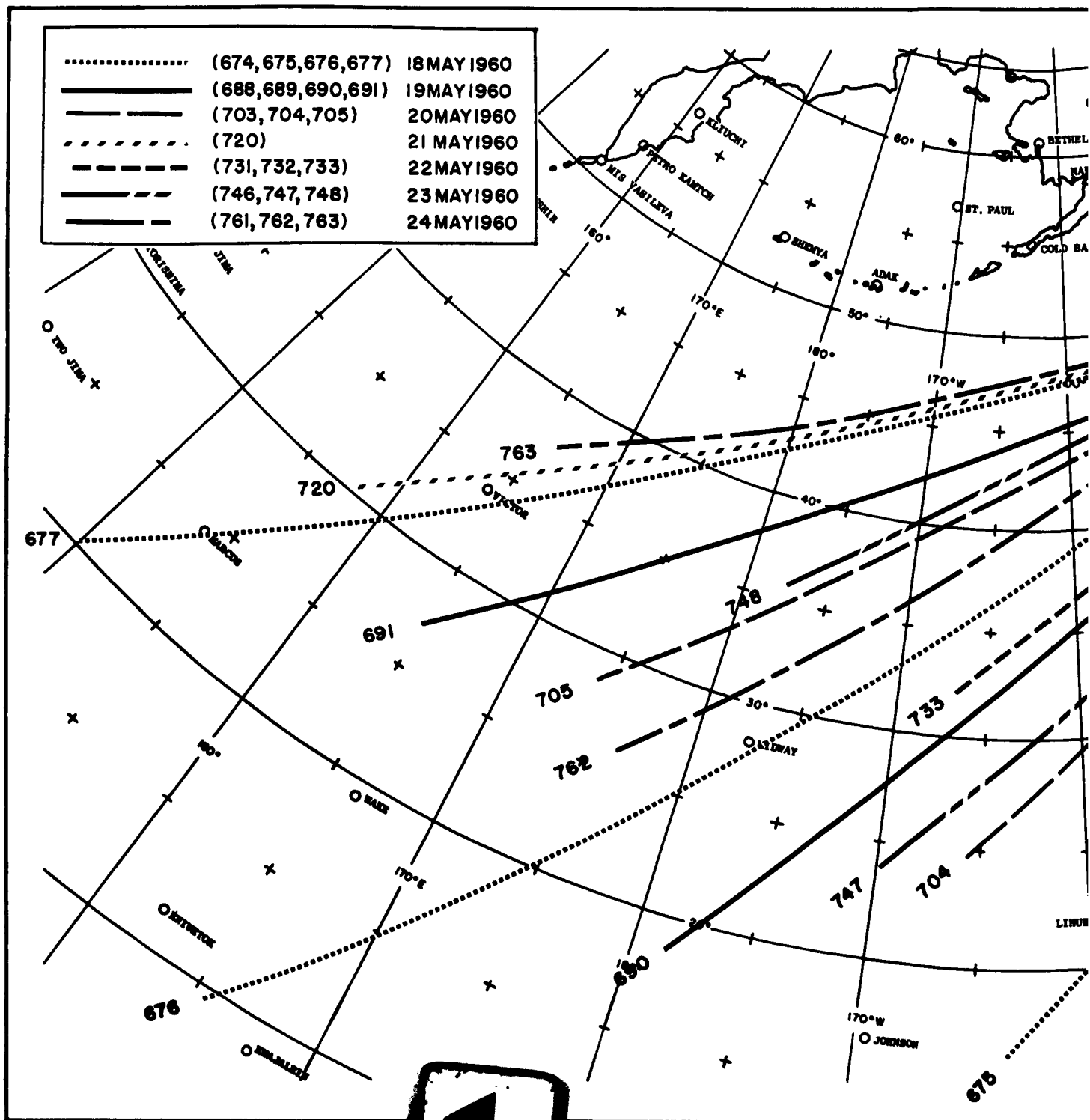


FIG. 1 PATHS OF ORBITS UTILIZED IN

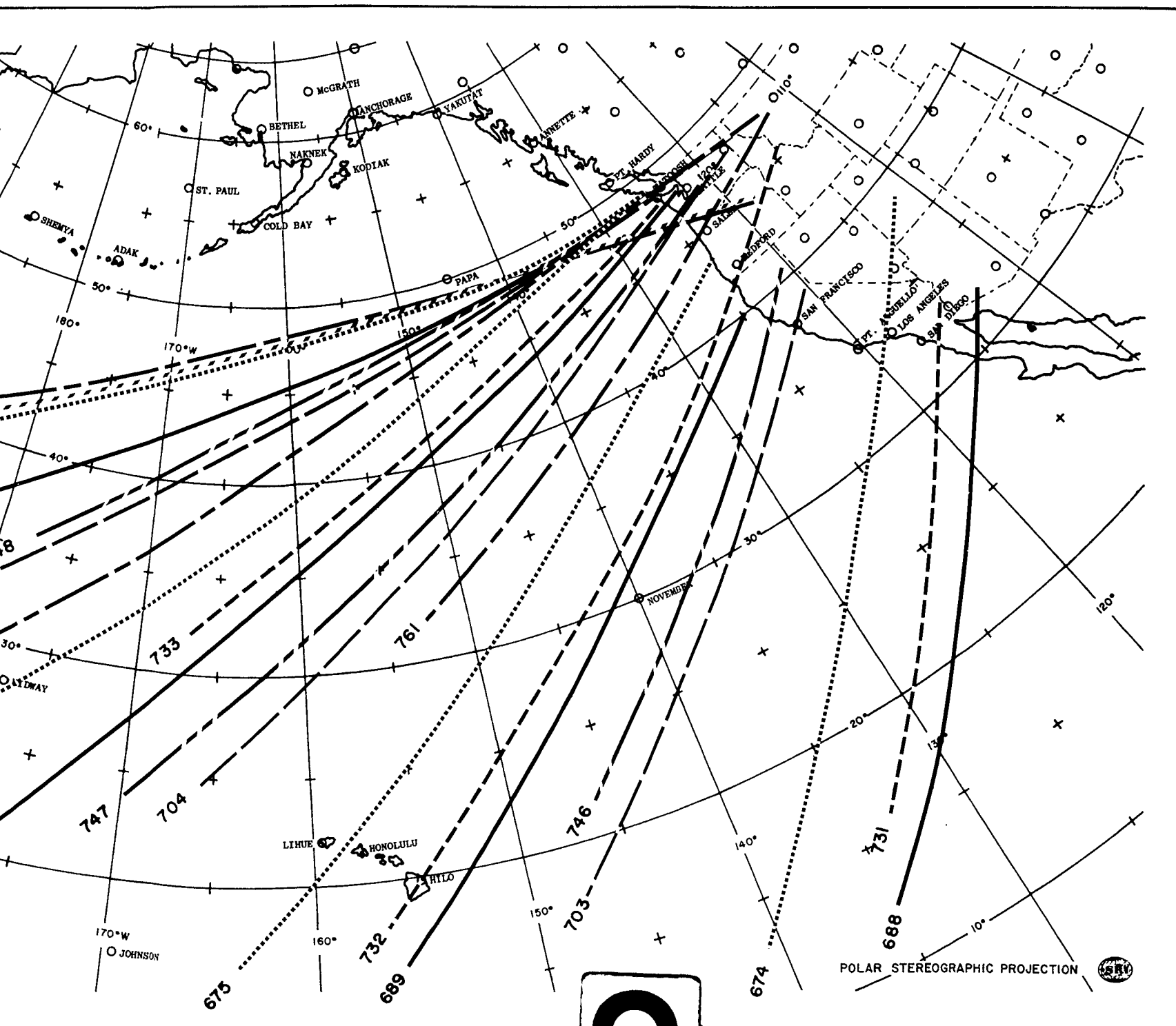


FIG. 1 PATHS OF ORBITS UTILIZED IN THE PACIFIC

FIG. 1

Table I  
TIMES OF SATELLITE PHOTOGRAPHS

Orbit	Date	Pictures Start (GMT)	Pictures End (GMT)
674	17 May 1960	2133	2143
675	"	2312	2318
676	18 May 1960	0052	0107
677	"	0233	0247
688	"	2042	2049
689	"	2222	2234
690	19 May 1960	0002	0016
691	"	0141	0156
703	"	2131	2141
704	"	2307	2312
705	20 May 1960	0055	0108
720	21 May 1960	0142	0158
731	"	1947	1954
732	"	2130	2138
733	"	2312	2321
746	22 May 1960	2037	2044
747	"	2218	2228
748	23 May 1960	0000	0013
761	"	2129	2137
762	"	2308	2319
763	"	0050	0102

compared with synoptic features. Detailed studies of cloud elements near the limits of each photograph can only be made from the individual photographs, since the actual geographical relation of clear air to cloudiness is not always true on the mosaic, due to the mechanical problems inherent in its construction.

Basic synoptic data were obtained from the U.S.W.B. Northern Hemisphere charts for the surface, 700-, 500-, and 300-mb levels, and the U.S.W.B. Daily Series of Northern Hemisphere Data Tabulations.

## II SYNOPTIC INTERPRETATION OF PHOTOGRAPHS

In the discussion that follows, illustration material is presented for each of the days from May 18th through May 24th. This material consists of the surface data and analysis, the 300-mb-level data and analysis, a mosaic of actual cloud pictures for each orbit with the jet stream and selected radiosonde plots added, and an artist's representation of the rectification of the complete coverage of clouds gleaned from all orbits, with the frontal and jet-stream analysis added. Letter identifiers are included on each illustration to facilitate cross-reference and location of various areas as they are discussed in the text.

### A. 18 May 1960

The major features of the surface map (Fig. 2)\* are a subtropical anti-cyclone centered near 36°N, 140°W, an extensive low-pressure area south of the Aleutian Chain and a frontal-wave family with two occlusions, one in the western Pacific, and the other near OSV Papa (50°N, 145°W). The latter occlusion is weak and no longer extends into the center of the parent low, south of the Aleutian Chain.

At the 300-mb level (Fig. 3) there is a broad long-wave ridge in the Eastern Pacific, and one closed low-pressure area just south of the Aleutians and another in the Western Pacific near OSV Victor (34°N, 164°E). The location and development of the jet stream, as analyzed on the 300-mb map, is shown by the portrayal of the axis and the isotach field of 50, 75, and 100 knots, respectively. The available cloud pictures (Fig. 4), utilized for this day were taken from Orbits 674, 675, 676, and 677. Figure 5 is the rectification of these orbits.

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\* Figures pertaining to a particular day of observations are presented at the end of the section in which that day is discussed.

### Orbit 677

This orbit begins southwest of Marcus Island and continues on a northeastward course, passing just east of OSV Victor, until it reaches OSV Papa.

As it proceeds from west to east, the orbit transits the following significant synoptic features: the developing occlusions west of D, a post-frontal area near B, and the occluded system near OSV Papa. The large, fairly dense cloud-mass distribution, particularly north of position D on Orbit 677, has the appearance of an occluded wave described in a study by Boucher and Newcomb (1962). The over-running cloud shield between C and D is associated with a tongue of moist air extending eastward of the occlusion. The clear area to the southeast of this cloud mass has been shown by Bergeron (1951) to be a characteristic feature of the distribution of cloud cover near an occlusion in this stage of development. The line of cloudiness extending westward from D fits rather closely to the cold front shown on the surface map (Fig. 2). The cloud cover in the warm sector ahead of the front, between D and E is probably the result of low-level convergence occurring in the warm maritime tropical air which is moving towards the northeast. The clear area behind the front is undoubtedly associated with subsidence occurring in the post-frontal colder, drier air.

The analysis of the jet stream in the Western Pacific shows two speed maxima over the Japanese Islands extending into the Pacific to approximately 165°E. The northernmost one parallels the cloud cover extending westward from the occlusion. The southern jet stream crosses the clear area west of the surface low-pressure center and continues eastward across the warm frontal cloud deck, diminishing in speed to below 75 knots in the clear area south of the major prefrontal cloud cover. The jet stream reaches maximum speed in the southern portion of the trough at 300 mb. East of 170°E the wind field weakens, accompanying the divergence of the contours in the area of frontal overrunning. Between 163°E and 170°E the isotach field associated with the northernmost jet stream diminishes to less than 50 knots and the location of the axis becomes uncertain.

Analysis shows an interruption in the axis of the jet stream, although east of the occlusion the jet stream reappears in some strength. A little farther to the east another isotach maximum appears just north of the leading edge of the cloud shield at C; this continues eastward as a single system to North America.

A ship to the west of C reported the periphery of this overrunning cloud shield to be altocumulus and low cumulus. The cloud field to the east of C is of distinctly different character, consisting of small, widely spaced cloud elements. This area was under the influence of cold, maritime air, moving from the west with a slight cyclonic trajectory. The spacing of the cloud elements and the absence of high clouds would tend to indicate that the air mass is fairly dry in the upper layers, limiting vertical development. Ship reports indicated that the majority of clouds in this region were of the cumulus and stratocumulus type.

Cloud photographs south of a line projected between C and A on this orbit show some evidence of long, straited, thin bands of clouds. Northward of this projected line between C and A the clouds show less alignment. Such changes in alignment may have analytical utility. Brunt (1951) has shown that in the case of convective clouds, the vertical wind shear is more pronounced over clouds that tend to align themselves in bands than it is over those of random distribution. This in turn implies that north of the projected line from C to A the horizontal temperature gradient is steeper than it is south of the line from C to A. Analysis of the jet stream places it almost on the line between C and A. The portion of the isotach field in excess of 100 knots extends from about 170°W (B) to the west coast of the United States.

#### Orbit 676

This picture series begins some 600 miles south of Wake Island, passes over Midway Island, and continues to Seattle (see Fig. 5). The mosaic (Fig. 4) shows the cloud field in the subtropical region (south of D), a cold-front cloud shield (from D to B), and a warm-front cloud shield (west of A). The frontal system shown on the extreme eastern edge

of the mosaic of Orbit 677 is the same as the one shown north of B and west of P on Orbit 676.

Ships in the area south of D reported these clouds to be of a swelling cumulus character, with some altocumulus and cirrus. Perusal of the cloud pictures shows the clouds to be of fairly bright intensity. From the ship reports one might suspect the existence of cirrus plumes (reported as caps). In the photographs these features are hardly identifiable beyond the recognition of some thin, filmy streaks. Those few that can barely be identified, in the horseshoe-shaped cloud cluster south of D, seem to extend southeastward. The bright spot just south of the center of a line between D and E is a sun glint and not a cloud.

Between D and B, the cloud field is associated with the front between the two occlusions. Ships just north of the frontal band reported layers of upper clouds, both cirrus and altostratus. These appear in the pictures as thin, fibrous, elongated cloud elements. These clouds appear to be present as far north as the jet stream axis.

The photographs in the Eastern Pacific at positions A, P, and B show the frontal overrunning clouds (P to A) and the cloud field resulting from convergence in the warm sector of the frontal system (area around and east of B). The clouds in the warm sector at B are associated with convergence in the tropical maritime air moving northeastward, and are similar to those in the warm sector of the frontal system in the western Pacific. Ships in area B reported fog and stratocumulus as the dominant cloud type. The jet stream lies over the northern periphery of the overrunning frontal clouds (see P to A). East of A the cloud pattern changes character to a more patchy and scattered appearance where divergence is occurring in the low-level northwesterly flow. The jet stream crosses the coastline near Seattle.

#### Orbit 675

The path of this orbit extends northeastward from southwest of the Hawaiian Islands, crossing the west coast between Salem and Medford, Oregon. It transits the southwest sector of the subtropical anti-cyclone

from C to A (see Fig. 5). Unfortunately, no pictures were available east of 140°W. The cloud cover in this sector of the anti-cyclone consists of bright clusters of clouds separated by extensive clear areas (see Fig. 4). South of A and east of B near the southern edge of the mosaic there are faint bands of elongated clouds somewhat fibrous in appearance. A ship in the area reported stratocumulus and altostratus.

The zonal orientation of the clouds in the area just south of C might be a result of, or associated with, the direction of the subtropical jet stream, whose existence is suspected from the wind reports at Johnston Island (65 knots at 300 mb).

#### Orbit 674

Observations of interest from this orbit are restricted to the lower latitudes of the Pacific off Southern California. The orbit transits the southwest sector of the subtropical anti-cyclone. Part of the extensive cloud cover evident around the southeastern and eastern perimeter of the anti-cyclone is probably due to an earlier southward surge of cold air along the west coast of North America. The cloud cover between B and C may be characteristic for that of a diffuse cold front in low latitudes. In this case, the front is probably the weak cold front extending westward from the low-pressure area over southern Nevada.



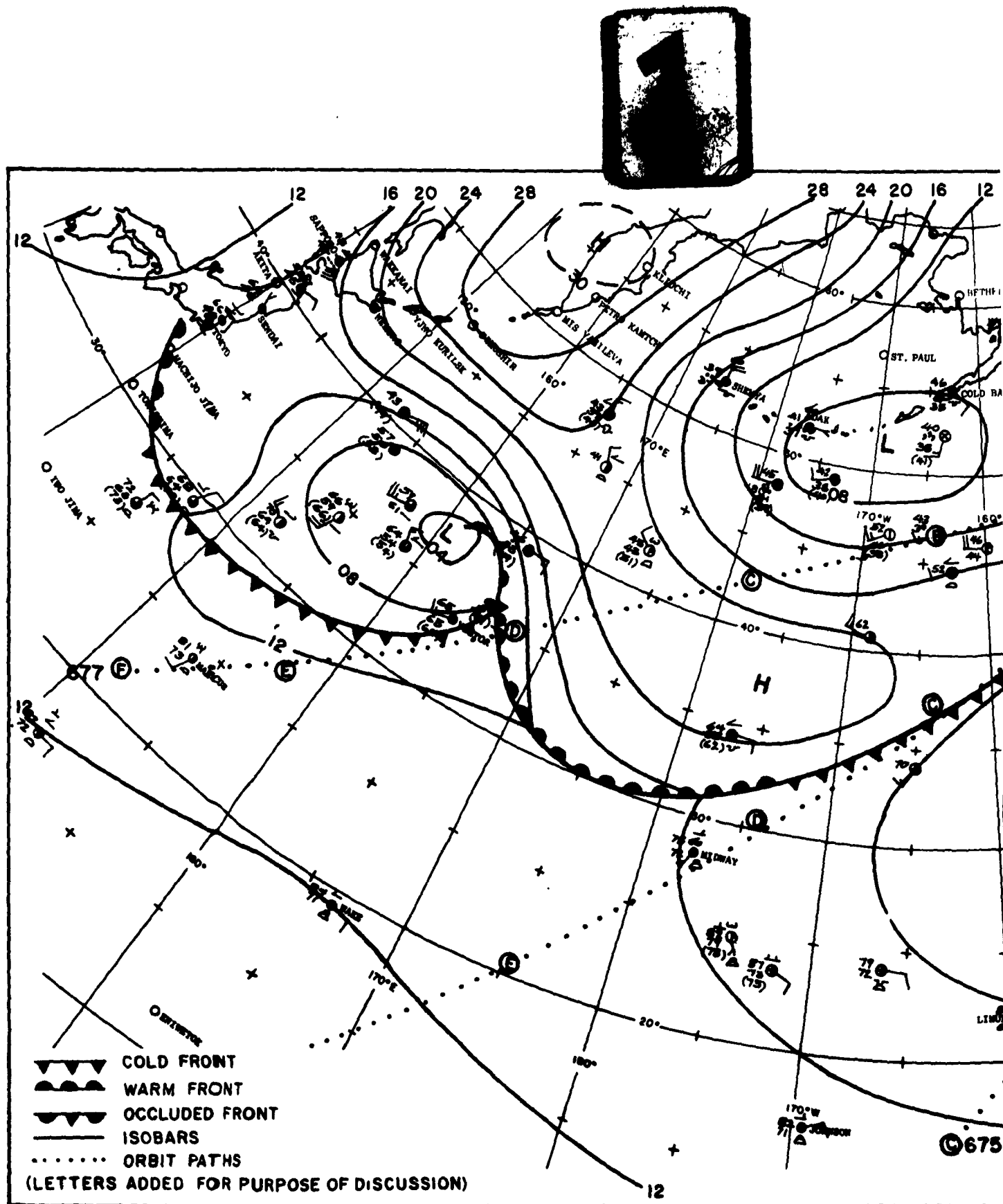


FIG. 2 SURFACE MAP, 18 MAY

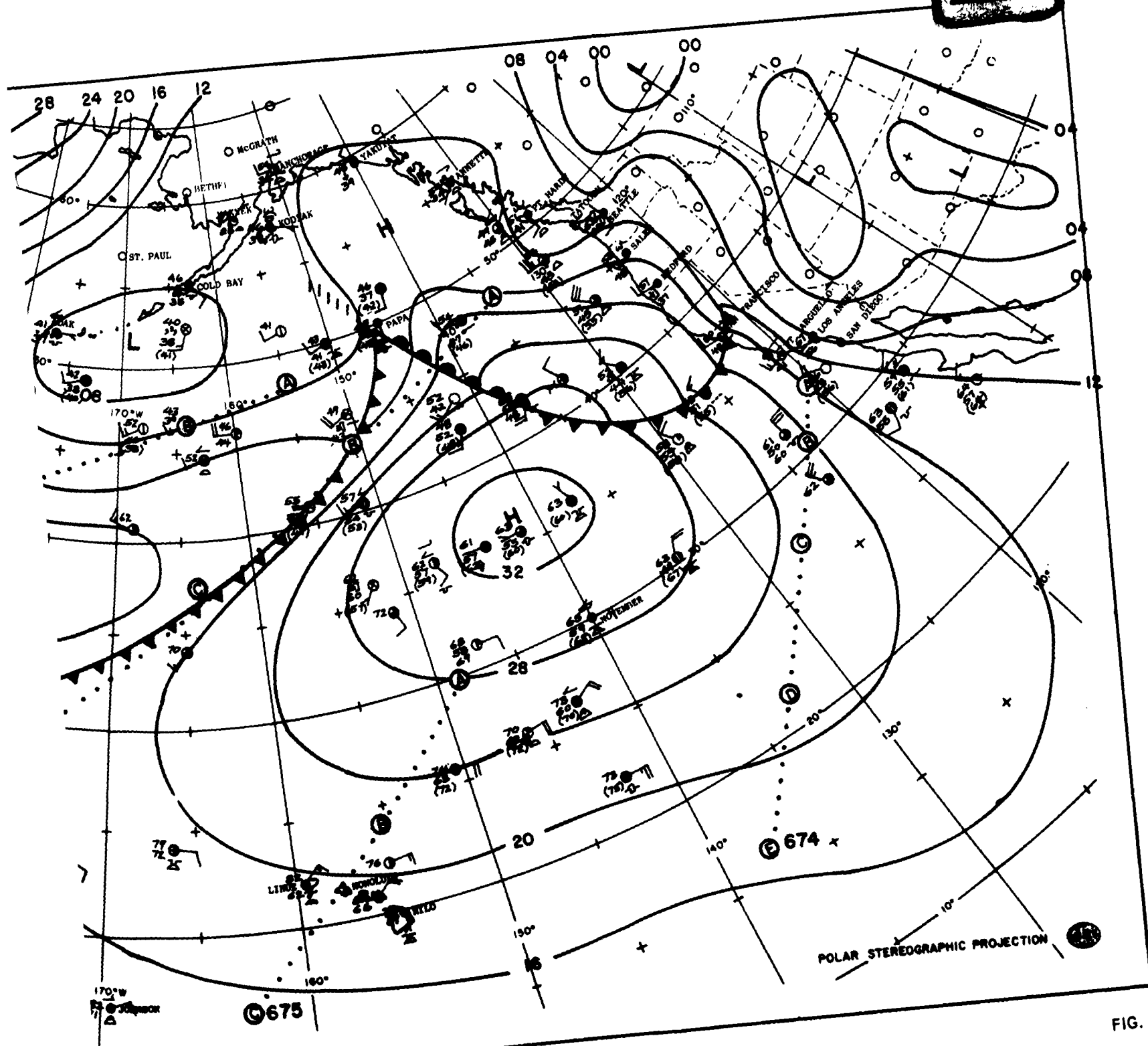


FIG. 2

2 SURFACE MAP, 18 MAY 1960, 0000 G.M.T.

— ISOPLETHS OF HT. IN HUNDREDS OF FT.  
 - - - ISOTACHS  
 → → → JET STREAM AXIS  
 ..... ORBIT PATHS  
 (LETTERS ADDED FOR PURPOSE OF DISCUSSION)

FIG. 3 300-mb MAP, 18 MAY 1968

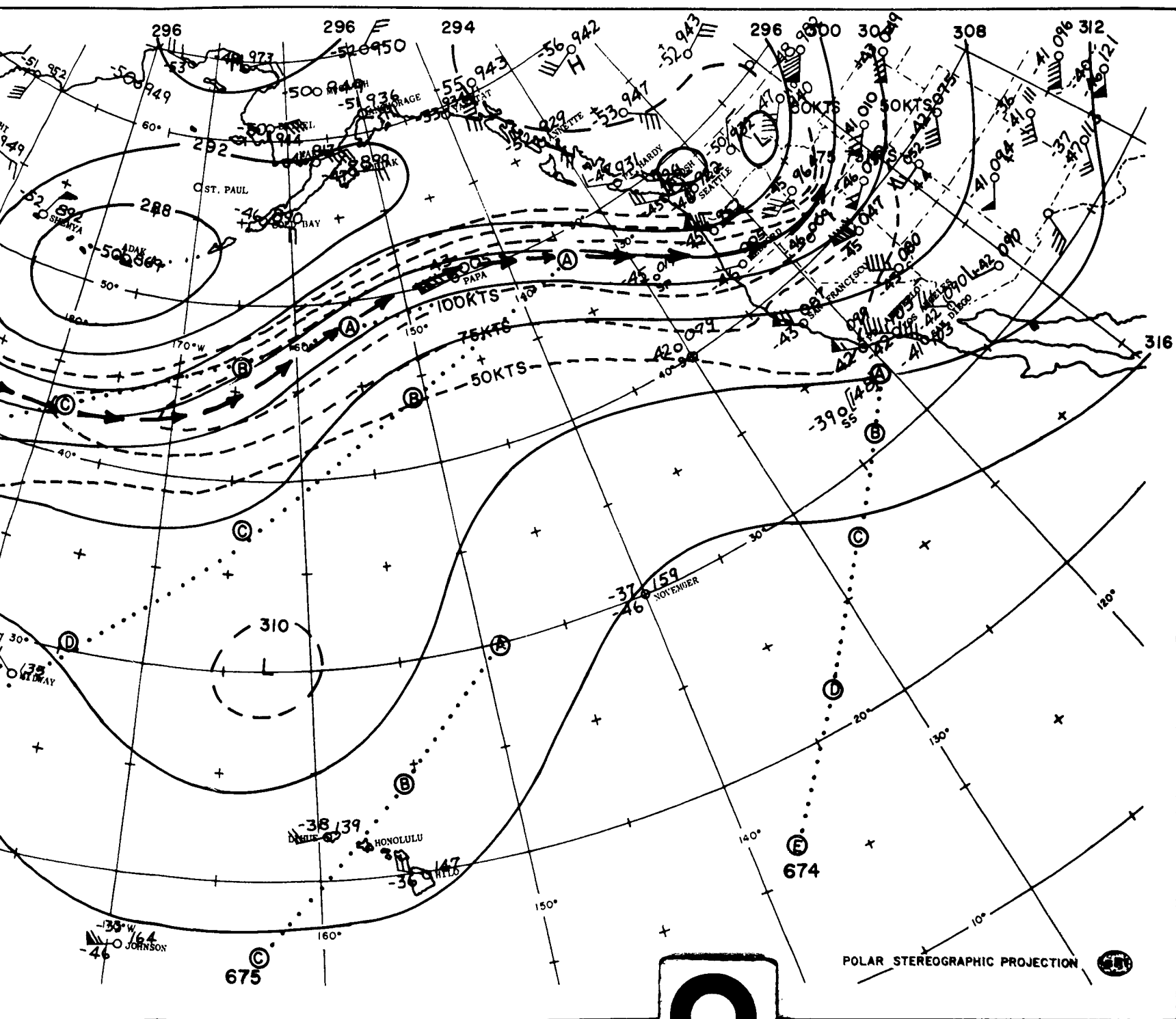


FIG. 3 300-mb MAP, 18 MAY 1960, 0000 G.M.T.

FIG. 3

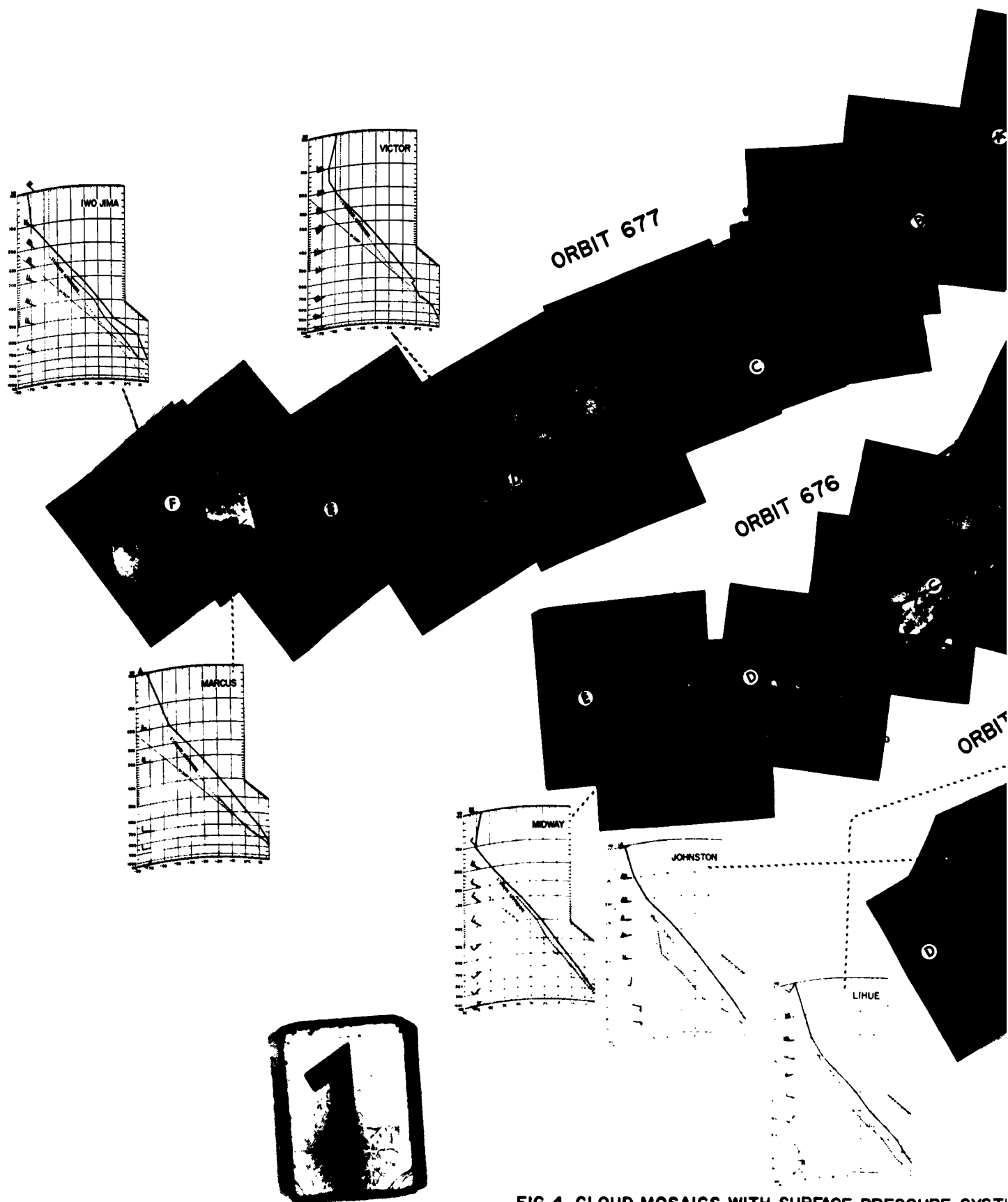
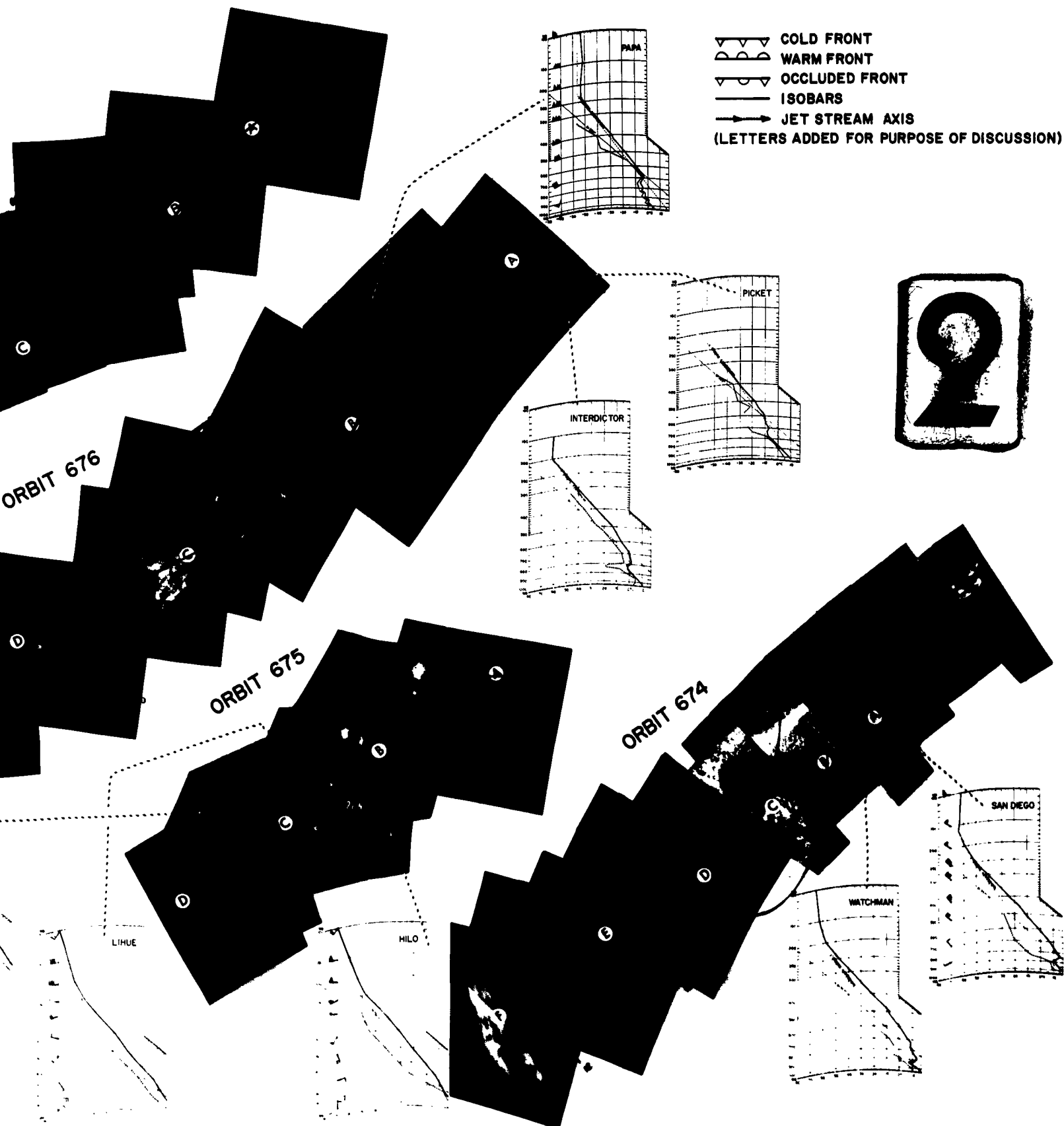


FIG. 4 CLOUD MOSAICS WITH SURFACE PRESSURE SYSTI



WITH SURFACE PRESSURE SYSTEMS FOR 18 MAY 1960, 0000 G.M.T.

FIG. 4

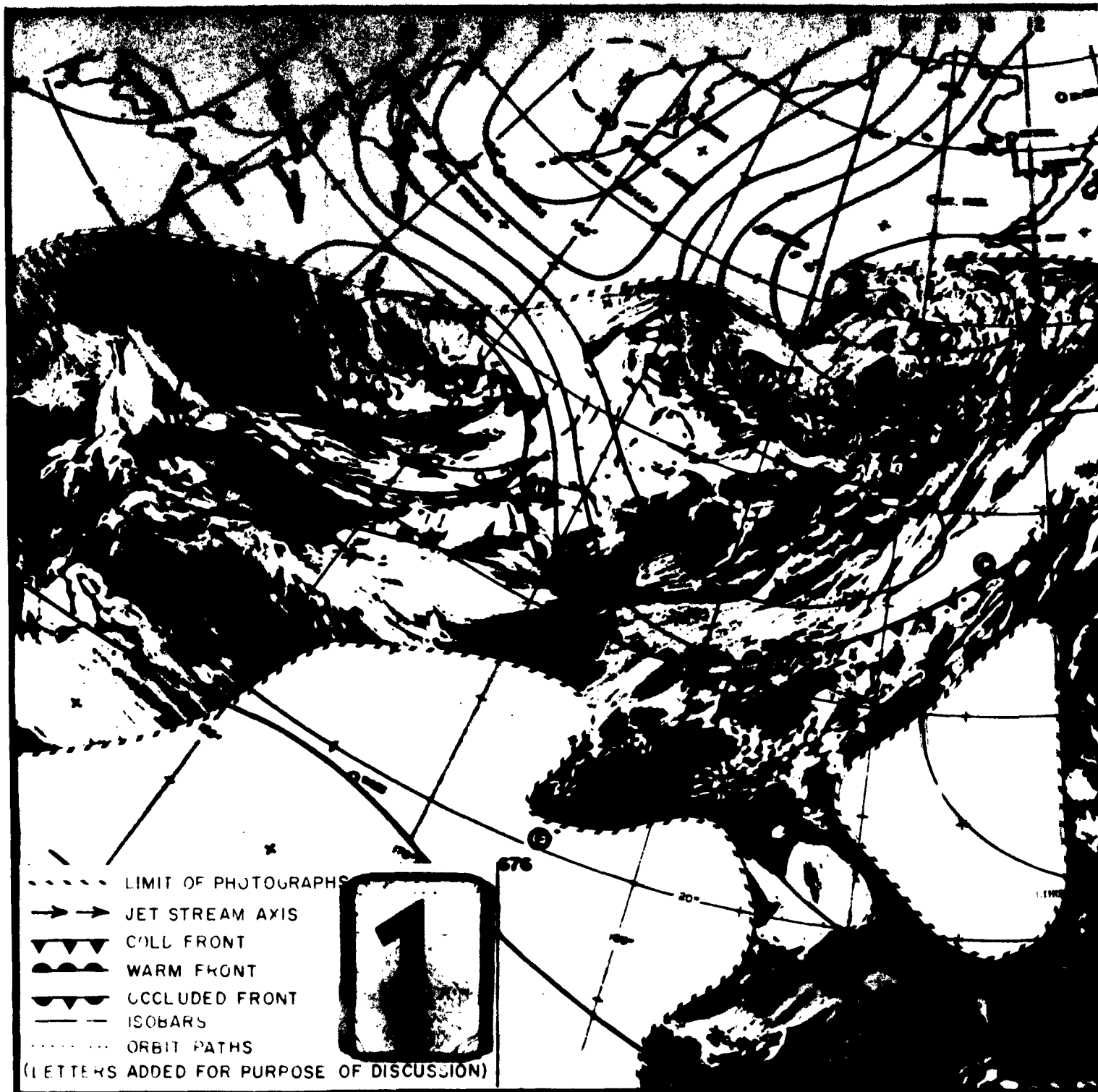


FIG. 5 RECTIFICATION OF CLOUD PHOTOGRAPHS



IFICATION OF CLOUD PHOTOGRAPHS, 18 MAY 1960, 0000 G.M.T.

FIG. 5



B. 19 May 1960

The surface synoptic pattern for May 19th (Fig. 6) remains essentially unchanged from that of the previous day. The cyclone in the Western Pacific continued to deepen as it moved some 600 miles eastward; the low-pressure area near the Aleutian Islands filled. In the Eastern Pacific the wave system remains unchanged in intensity and now appears near the coast of British Columbia. The major sub-tropical anti-cyclone has also moved eastward though now a well-defined, additional lobe of high pressure exists (south of C in the photographs for Orbit 691) north of the cold front between the low-pressure centers in the Eastern and Central Pacific.

The 300-mb analysis (Fig. 7) shows a ridge aloft over the surface frontal system off the west coast of the United States. Inland, downstream from this ridge, there is a well developed trough. There are also signs of the development of a weak trough west of OSV Papa. An intense meridional trough is developing in the Central Pacific, as the secondary upper low-pressure area associated with the deepening occlusion is drawn into main low near the Aleutians.

The cloud photographs available on this day were taken from Orbits 688, 689, 690, and 691 and are shown in mosaic form in Fig. 8. Figure 9 shows the rectification for the combined orbits.

#### Orbit 691

This orbit begins about 400 miles south of Marcus Island and extends northeastward across the Pacific, transiting the west coast of the United States over Seattle. It crosses the cold front in the West Central Pacific, passes almost over the point of occlusion of the deepening system in the Central Pacific between F and E, over the lobe of the anti-cyclone developing between D and B, and finally across the frontal system off the coast of British Columbia.

The overrunning cloud shields associated with both wave systems are beginning to assume a vortex-like pattern (see E and A). In the Central Pacific the prefrontal cloud shield extends north of D and almost to C. The frontal cloud band associated with the warm-front portion of the system

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is evident towards the southern edge of the mosaic below D and E. In the warm sector south of F and E there is an extensive band of amorphous clouds associated with convergence occurring in the warm, tropical air as it moves northeastward. Ships in this area reported cirrus, alto-cumulus, altostratus, and low cumuliform types of clouds. The post-frontal clearing (north of F) is quite marked. The edge of the returning cloud shield around the north side of the occlusion is evident at the top of the mosaic north of E.

The 300-mb-level analysis shows two jet streams in the western Pacific. The northernmost one extends eastward along the northeastern perimeter of the ridge (beyond the area for which photographs are available), and southward into the trough associated with the cyclone centered on 170°E. The axis of this jet stream extends over the clear area just to the south of the ring of clouds west of the occlusion near E. The isotach maximum is at the southern limit of the trough. From this region the jet stream axis extends eastward, proceeding over the clear area that extends as far east as the surface position of the occluded front. From that point on, the jet stream continues eastward over an area covered by the prefrontal cloud shield associated with the low-pressure area. It continues eastward almost parallel to the northern perimeter of this cloud shield until it emerges into the relatively cloud-free area downstream (from point E to P). Its point of emergence is the edge of what appears to be a pronounced extension of the prefrontal cloud shield (between C and D). In this area the orientation of the jet stream appears to parallel striations in the cloud deck.

The cloud configuration in the central Pacific reflects quite accurately the shape of the isentropic tongue of warm, moist air that is an integral part of a deepening, extra-tropical cyclone.

In the central Pacific there is a second jet stream south of the one just discussed. At the southern limit of the trough the two jets are separated by about 2 degrees of latitude and are approximately parallel to each other. Ships in the area underneath this southern jet reported some scattered cumulus and stratocumulus clouds. (Again, the apparent

orientation of these clouds is parallel to the jet stream above, but the reality and significance of such an orientation is presently uncertain.) Continuing eastward, the jet stream runs over a predominantly clear area until it crosses the front near the point of occlusion (E). Beyond this point it proceeds across the prefrontal cloud shield, continues to about 170°W where it weakens along the northern periphery of the warm frontal overrunning, and is no longer considered as a jet stream.

In the previous 24 hours a decided decrease in amount of cloud cover accompanied the aforementioned intensification of the lobe of high pressure. For example, compare the cloud cover of May 18th in the area of the weak high-pressure ridge (south of point C on Orbit 677) with the cloud cover on this day associated with the well-developed lobe of high pressure (south of C on Orbit 691). The few clouds that are present in this area on this day are reported as middle and high clouds.

In the area east of C, westerly flow of cold, maritime, arctic air prevails. The cloud cover increases and is composed mostly of scattered clouds, reported as cumulus and cumulonimbus. Such conditions of sky cover are seemingly evident from the photographs, both as to amount and type of clouds.

From point C to the coast of the United States the jet-stream configuration almost parallels the cloud system associated with the cold front to the south (see Orbit 690). Throughout the major portion of the area the jet stream is well north of the frontal cloud deck. The jet stream crosses this cloud deck only in the eastern Pacific near the point of occlusion of the frontal system.

#### Orbit 690

This orbit begins about 500 miles south of Midway Island and extends northeastward to Seattle. It parallels a frontal system from E to C, and then crosses a warm front off the Washington coast. South of the frontal system in the subtropical latitudes (G and F) the cloud cover, as seen in the photographs, is composed of scattered patches of bright cloud. Ships in this area reported only low cumuliform cloud types. South of F there

was one report of shower activity. Along the frontal system between E and D where the front separates the two high-pressure cells the cloud field is somewhat fragmented and thin as compared to the cloud cover in the area from D to C where the frontal contrast is more pronounced. Between C and A there is the now familiar and probably characteristic warm-sector amorphous cloud shield. Ships south of B reported overcast conditions with low stratus and stratocumulus clouds, indicating stable conditions in the lower layers. West of the jet stream axis near A the cloud cover seems to be organized into thin, fibrous rows oriented almost parallel to the contours of the high-pressure ridge aloft. Coastal stations near A reported middle and high clouds.

#### Orbit 689

This orbit begins some 500 miles south of the Hawaiian Islands and extends northeastward, crossing the West Coast of the United States between Medford and San Francisco. Prior to reaching the California coastline this orbit transits just southeast of the center of the eastern Pacific anti-cyclone. Between D and C in the region to the southwest of the subtropical high-pressure cell the satellite transits alternating rows of clouds and clear areas. The cloud cover is much more extensive in the southwestern sector of the subtropical high. Here, clouds are rather bright in appearance and seem to be arranged in rows roughly perpendicular to the surface wind flow. The extensive area of clouds east of C is probably related to a previous surge of cold air. This type of cloud character (mostly cumuliform) may be typical of divergent southward-flowing air in low levels. By comparison, the western portion of the subtropical high cell is relatively free of clouds.

#### Orbit 688

This orbit extends northeastward from the tropical Pacific into Lower California, traversing the extreme southeastern perimeter of the subtropical anti-cyclone. The cloud cover along this orbit is quite extensive, mostly cumuliform (ship reports identified the clouds as stratocumulus), arranged in broad streets. In the area between C and B the cloud cover is a continuation of the widespread cloudiness in the region between C and B on Orbit 689.

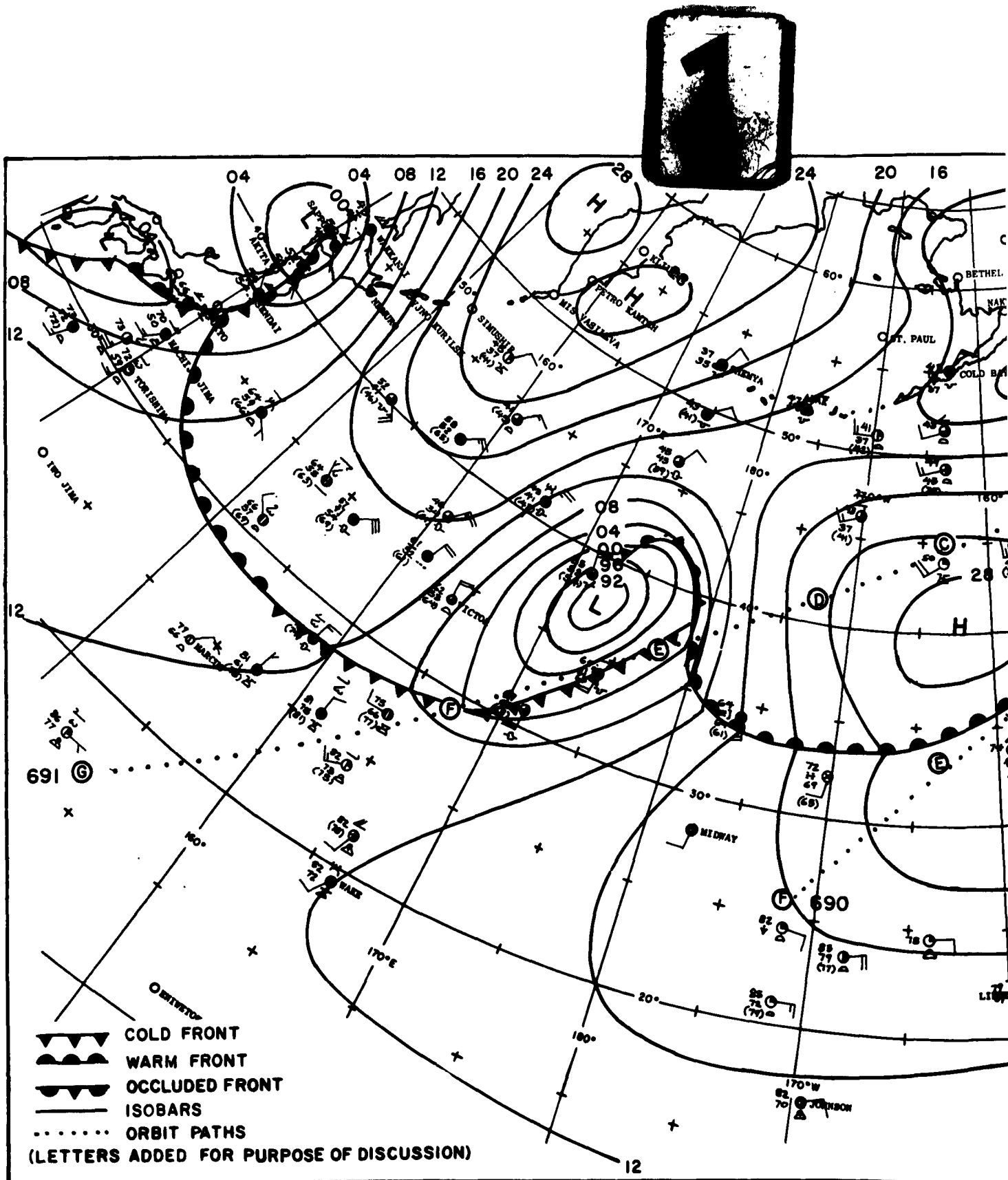
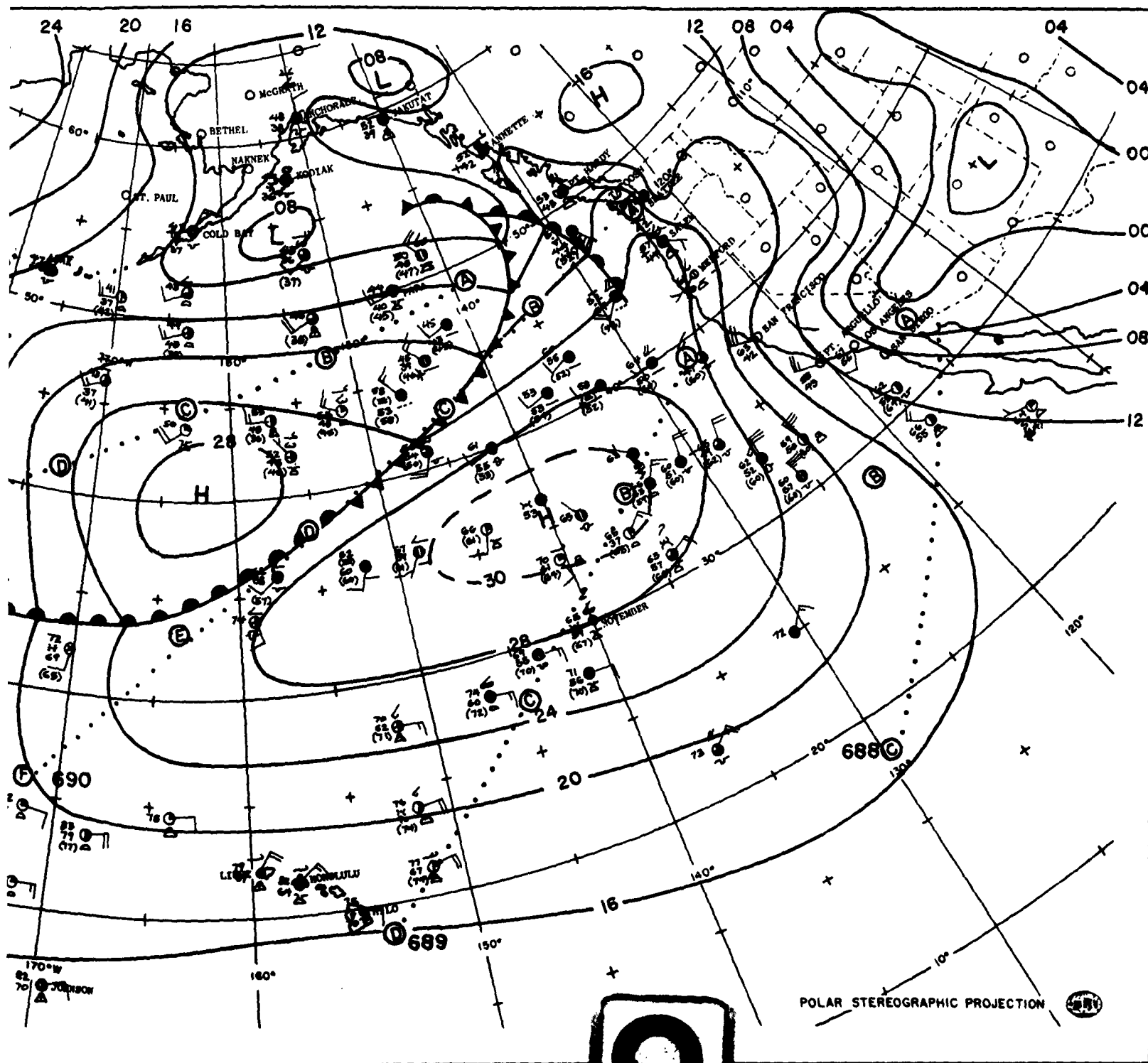
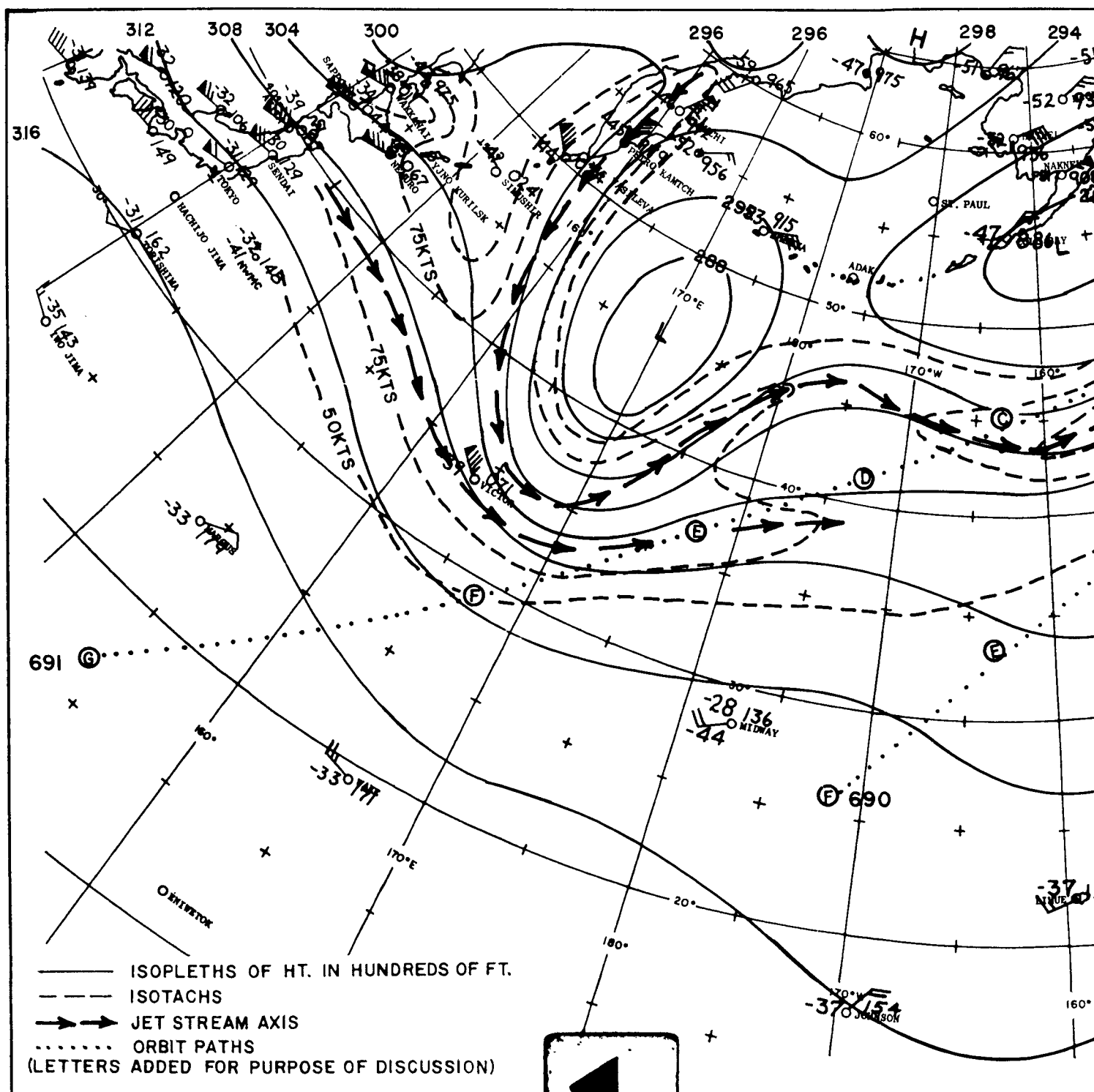


FIG. 6 SURFACE MAP, 19 MAY 1961



G. 6 SURFACE MAP, 19 MAY 1960, 0000 G.M.T.

FIG. 6



1

FIG. 7 300-mb MAP, 19 MAY 1960,

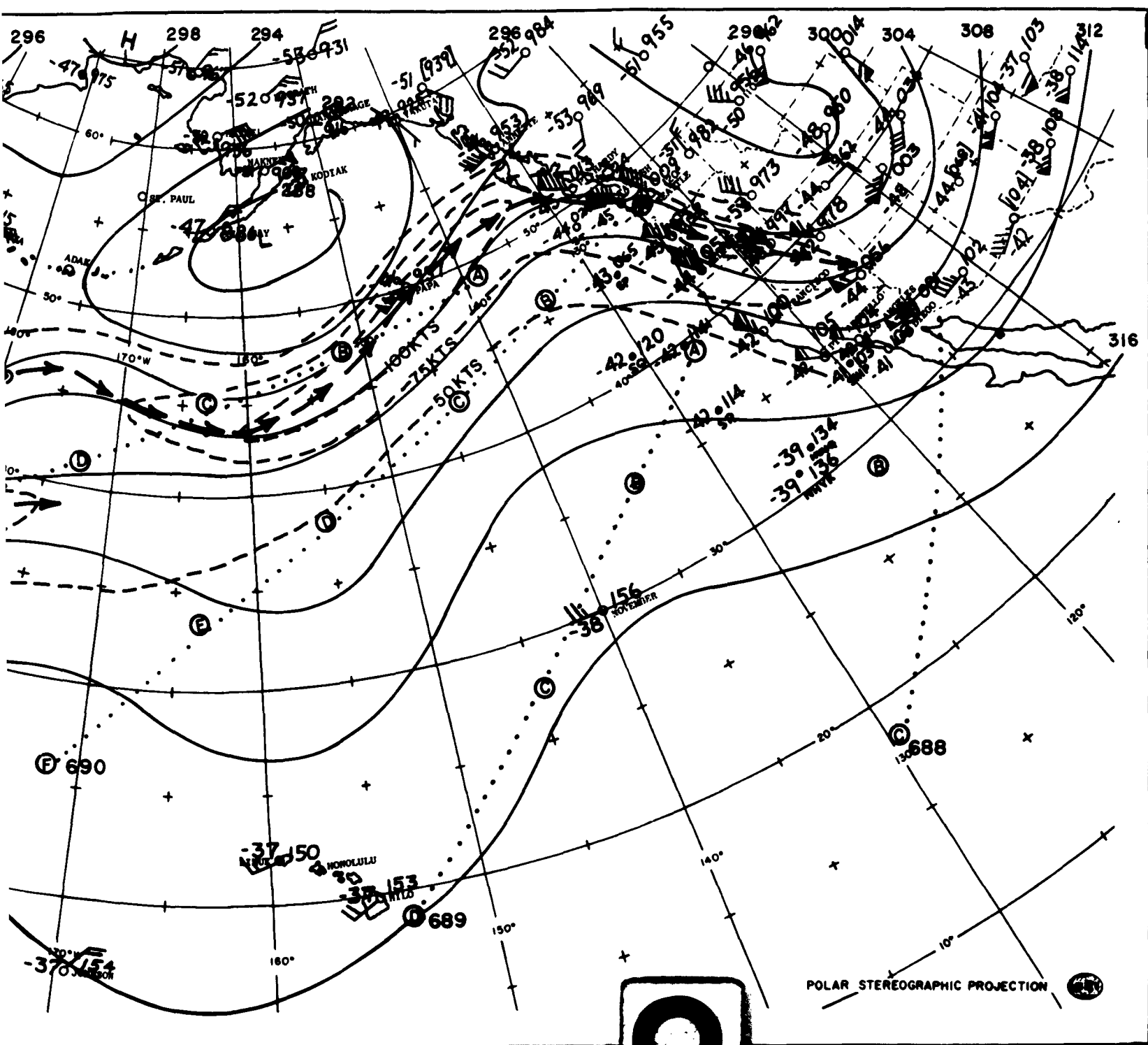
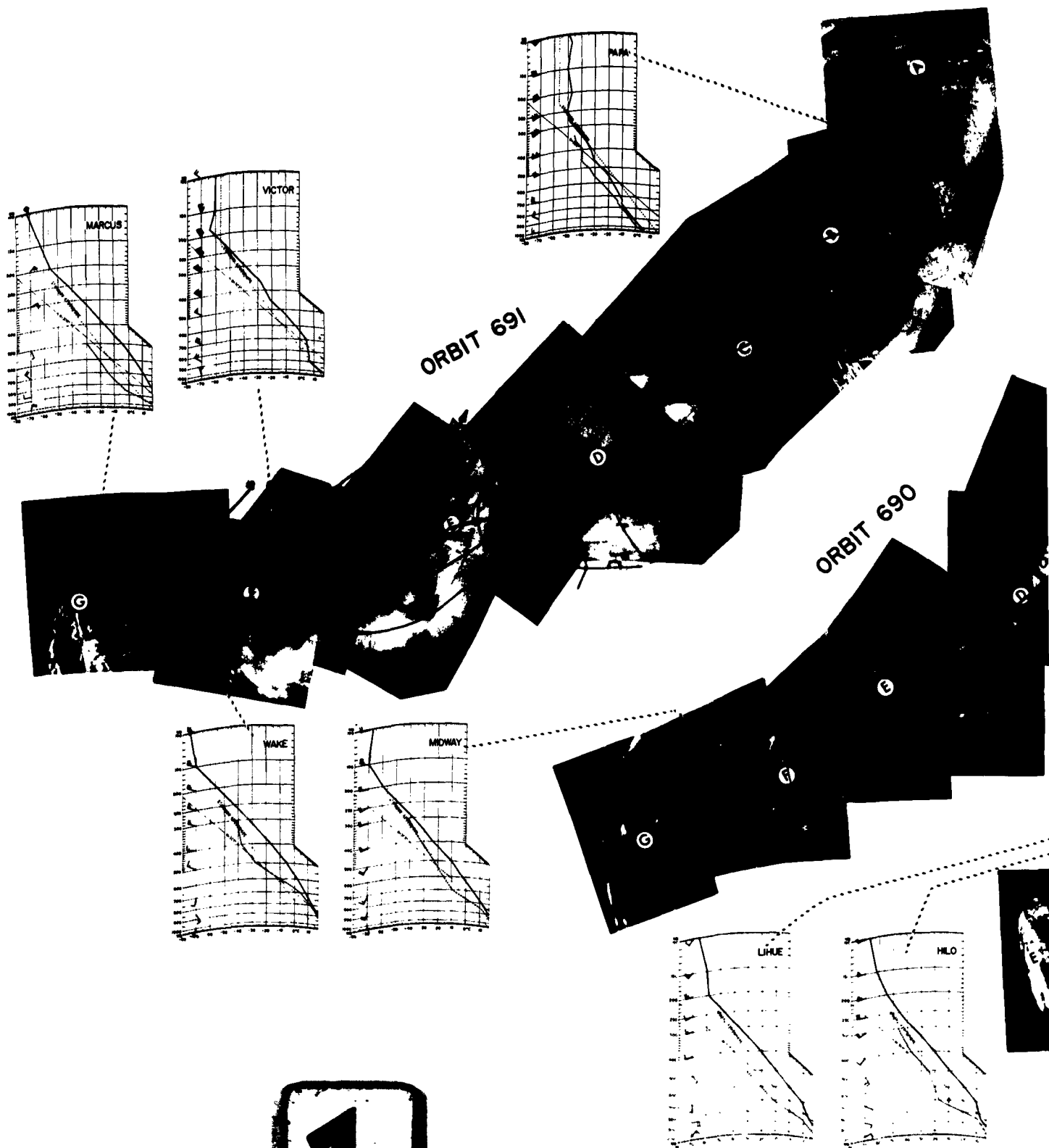


FIG. 7 300-mb MAP, 19 MAY 1960, 0000 G.M.T.

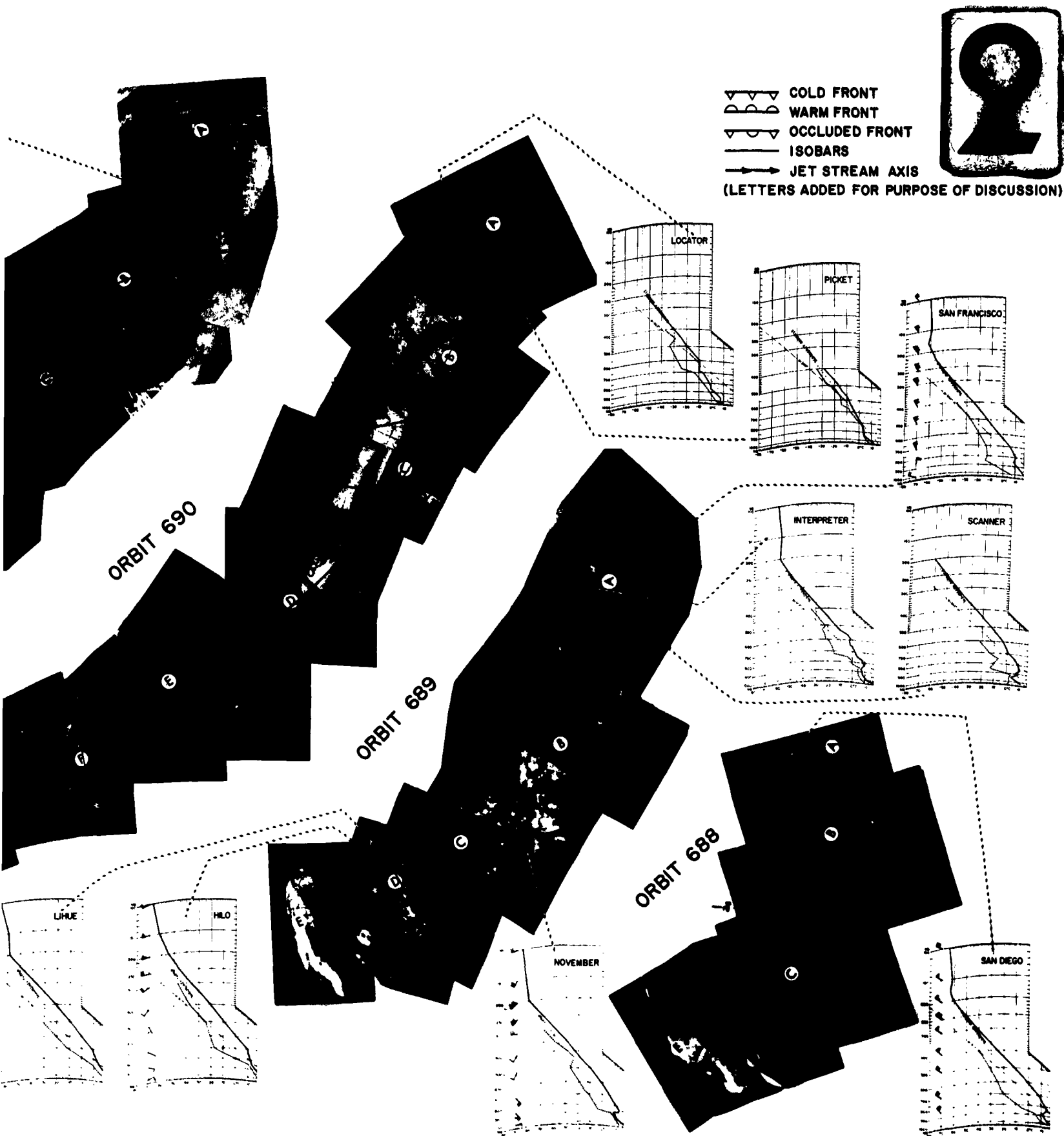
FIG. 7





1

FIG.8 CLOUD MOSAICS WITH SURFACE PRESSURE SYSTEM



CS WITH SURFACE PRESSURE SYSTEMS FOR 19 MAY 1960, 0000G.M.T.

FIG.8





FIG. 9

C. 20 May 1960

The wave system that was in the Gulf of Alaska on the previous day has now occluded and lies close to the coast of British Columbia (see Fig. 10). The cyclone in the Central Pacific has deepened and is now near 180°W. In the eastern Pacific the developing lobe of high pressure has moved eastward and, in part, is combined with the subtropical high.

The upper-air analysis (Fig. 11) shows further intensification of the cold cyclone, and its attendant trough, near 175°E. Off the west coast of North America the trough has deepened during the previous 24 hours, with a closed low-pressure area aloft centered almost directly above the surface low-pressure center.

Photo mosaics of clouds for this day (Orbits 703, 704, and 705) are shown on Fig. 12 and their rectification on Fig. 13.

Orbit 705

This orbit begins about 400 miles west of Midway Island and extends eastward, crossing the west coast of the United States over Seattle. It transits the post-frontal portion of the deep cyclone in the central Pacific (between G to F) just north of the cold front, and crosses the warm-front cloud shield somewhat south of the point of occlusion (near E). Further to the northeast it transits the northern extension (near D) of the lobe of high pressure. It then passes over the post-frontal area of the cyclone in the eastern Pacific (between C and A), crossing the cold front near A.

The clouds in the vicinity of the vortex in the central Pacific (top of photograph above F, in Fig. 12) exhibit the spiral configuration now considered characteristic of a well developed occlusion. The frontal cloud shield is seen between F and E, extending northward around the vortex. Ships under this shield reported obscured skies with fog predominating, and one report indicated drizzle. The brightness of the shield indicates that there is undoubtedly a substantial amount of middle and high clouds being advected or forming over the lower clouds.

The post-frontal area north of G and F is covered with a great deal more cloudiness (though still arranged in streets) than was present the preceeding 24 hours. During this time considerable deepening has taken place in the occluding system. Koteswaram (1961) has shown that the length and breadth of cloud streets is related to the intensity of convergence. Therefore, the evident increase of cloud cover in the previous 24 hours in this area may be an indication of the increased convergence accompanying the deepening of the low.

Two marked, downstream extensions of clouds emanating from the eastern periphery (about  $160^{\circ}\text{W}$ ) of the major cloud shield are shown on the rectification (Fig. 13). The northerly extension near Cold Bay, Alaska is not shown on the mosaic (Fig. 12), but the more southerly one (near  $45^{\circ}\text{N}$ ) is shown just north of D in Fig. 12.

When the analyzed position of the jet stream is superimposed on the cloud field, the maximum isotach area lies in the region of clearing around the vortex in the central Pacific (see area around F).

In the eastern Pacific the jet stream extends over the cumulus cloud cover in the cold air behind the front. In this region the axis of the jet stream is oriented almost at right angles to the cumulus cloud elements which appear more as lines than as cells. Such a configuration of the cumulus field is often indicative of the strong shear in the lower layers of the atmosphere under a jet stream. Ships south of the analyzed position of the jet stream reported the cloud cover as stratocumulus, while ships to the north reported cloud cover as cumulus and swelling cumulus. It is interesting to note that the orientation of the cloud lines is roughly normal to the surface wind flow and almost parallel to the wind shear vector between the surface and the 300-mb winds. This cloud cover in the cold air north of the frontal cloud is characteristic of fresh cold air travelling over warmer waters. The pictures show that the change from the occluded frontal clouds to the post-frontal cloud is abrupt and highly distinctive. The occlusion on the coast is accompanied by the spiral cloud band previously reported with this type of pressure system.

#### Orbit 704

Orbit 704 comes in west of the Hawaiian Islands and crosses the west coast of the United States over Seattle. It transits a frontal band of clouds between E and D and proceeds along the northern edge of this cloud band between D and B, recrossing it again in the eastern Pacific between B and A. This is the same frontal cloud band that is partially evident along the southernmost edge of the mosaic for Orbit 705.

In the frontal band of clouds the brightness of the cloud field suggests the presence of upper clouds along the front. The surface observers in the area reported overcast conditions with the cloud type unspecified. The post-frontal, broken cloud field to the north of the front on this orbit is the same, in part, as that seen on Orbit 705 from C to A. However, the prefrontal cloud shield is seen in its entirety on Orbit 704 between B and A. The cloud field east of A lies over the mountains in the state of Washington.

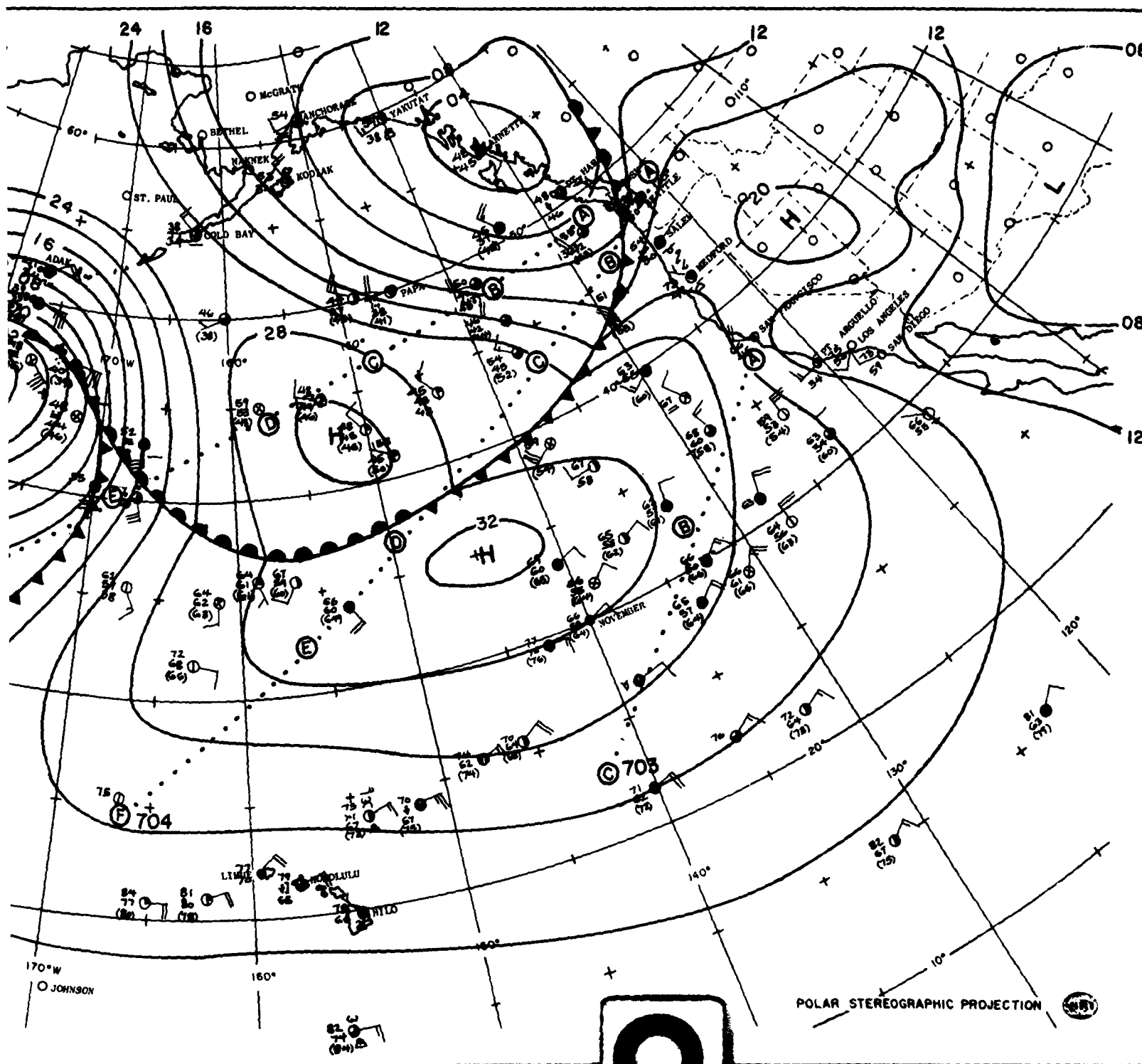
#### Orbit 703

Orbit 703 extends across the southeast sector of the subtropical high-pressure cell in the eastern Pacific and crosses the west coast of the United States over San Francisco.

South of the front, the subtropical high cell is covered by large groups of clouds with the exception of the southwest sector. The clouds in the vicinity of C are cumuliform in appearance, and are probably towering cumuli. Near B the clouds are more of the cumulus and stratocumulus variety as ship reports in these areas indicated. The clouds between B and A have more of a stratiform appearance, perhaps due to cooling of the air mass by upwelling cold water resulting from the northerly flow off shore. Ships in this area reported stratocumulus and obscured skies. In close proximity to the coast, the edge of this cloud shield near A is very distinct. From this point to the coast the entire area is predominantly clear. This cloud-free area is associated with the off-shore flow that is frequent along the California coast, southward from about 40°N.







5. 10 SURFACE MAP, 20 MAY 1960, 0000 G.M.T.

FIG. 10

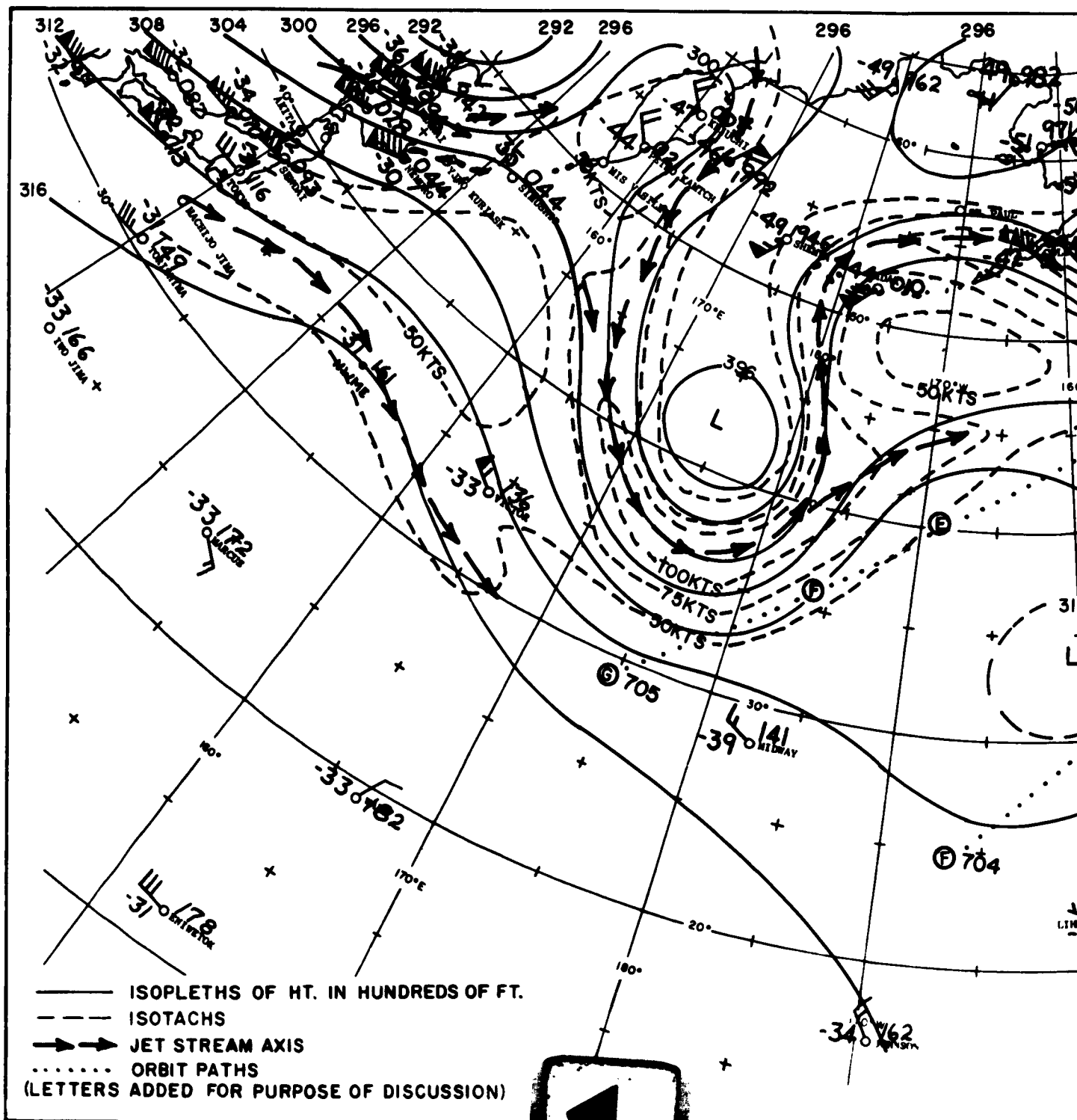


FIG. 11 300-mb MAP, 20 MAY



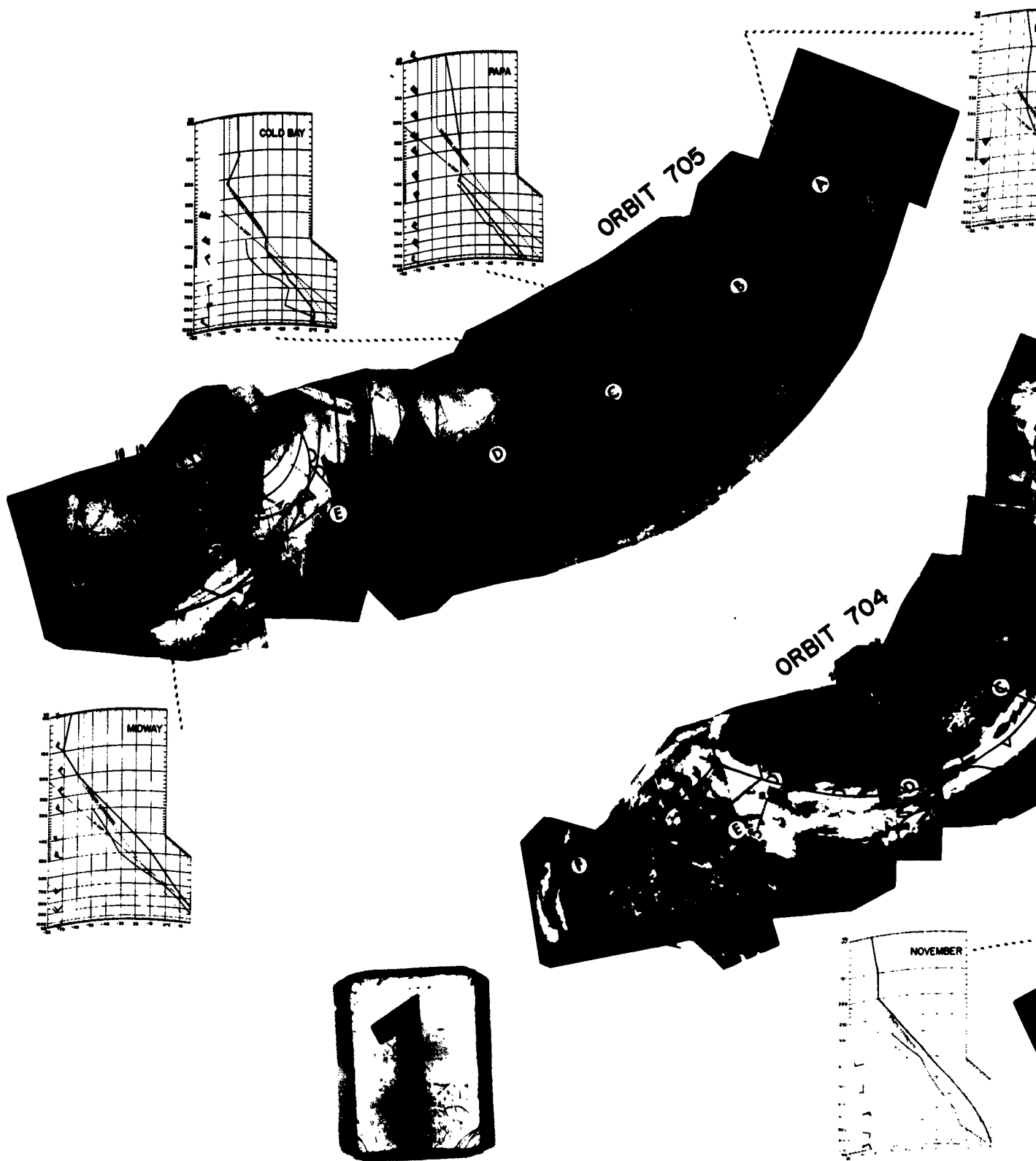
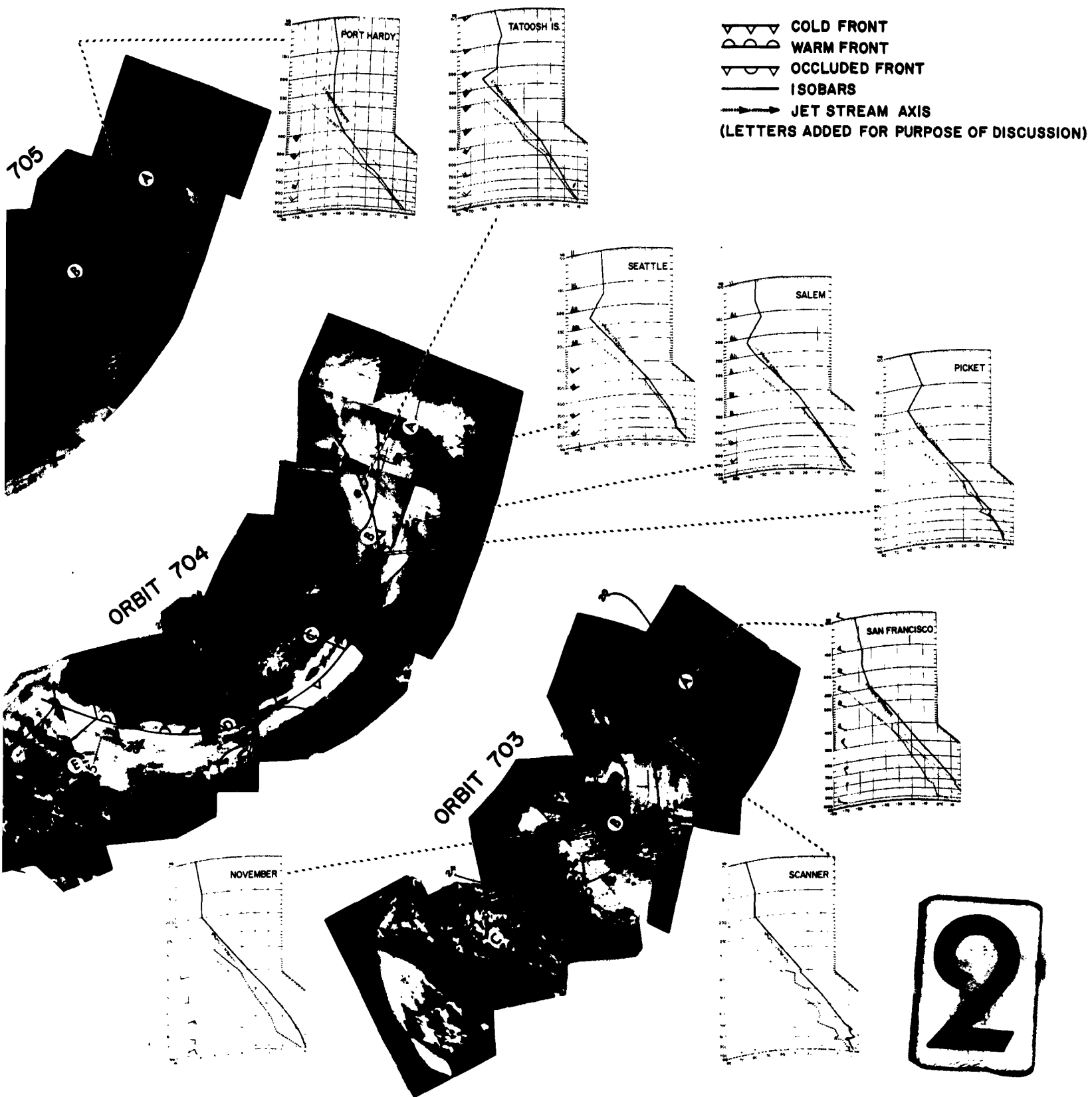


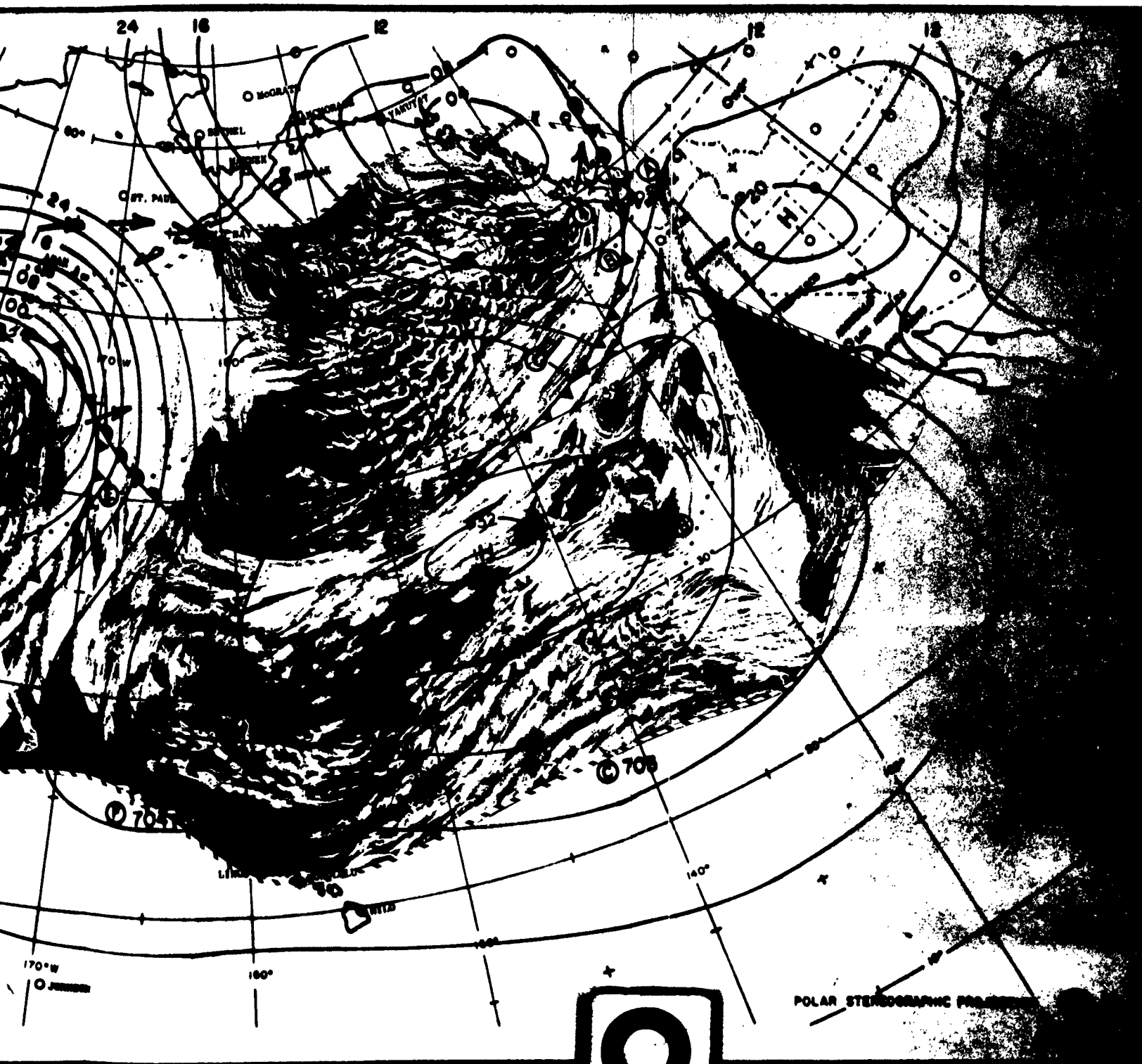
FIG.12 CLOUD MOSAICS WITH SURFACE PRESSURE SYSTEMS FOR 20 M



SURFACE PRESSURE SYSTEMS FOR 20 MAY 1960, 0000 G.M.T.

FIG. 12





IFICATION OF CLOUD PHOTOGRAPHS, 20 MAY 1960, 0000 G.M.T.

FIG. 13

D. 21 May 1960

The surface map (Fig. 14) shows that in the previous 24 hours the cyclone in the central Pacific moved toward the northeast and continued to be very intense. The occluded front which moved northward along the northeast periphery of this storm is now quite weak. Southwest of this disturbance there is now a well developed high-pressure cell, and a newly occluded system is moving into the western Pacific from the Japanese Islands. In the eastern Pacific the anti-cyclone has intensified and is now a single system with a pronounced ridge extending into northerly latitudes. The cold front associated with the cyclone previously off the coast of British Columbia is now inland over the western United States, crossing the coast near San Francisco.

The upper air analysis (Fig. 15) shows a series of pressure troughs and ridges of about equal amplitude across the Pacific. In the central Pacific the trough is almost superimposed over that of the well developed surface low-pressure area.

The photo mosaic of cloud cover for the single orbit available in the Pacific on this day is shown in Fig. 16, and the rectification is shown in Fig. 17.

Orbit 720

In the northern Pacific, Orbit 720 passes close to Marcus Island, over OSV Victor, and OSV Papa, and continues eastward crossing the West Coast of the United States near Salem, Oregon.

The orbit crosses a subtropical high-pressure cell between G and F, and passes (between E and D) just south of the well developed cyclone in the central Pacific, intersecting the point of occlusion of this intense storm about 100 miles east of D. Farther eastward it passes over a ridge just west of OSV Papa and over post-frontal clouds prior to reaching Salem, Oregon.

Beginning on the western edge of the mosaic (Fig. 16), the subtropical high (between G and F) is mostly cloud-free. Clouds that are present were reported by ships as primarily stratocumulus. There is



evidence of middle and high clouds near G and north of H. North of this subtropical high the ridge is covered by an extensive cloud sheet which extends from the advancing frontal system in the western Pacific. The brightness and general appearance of this extensive cloud shield suggests that it may be comprised of multiple cloud layers, although the majority of surface ships reported only a low overcast of stratus or stratocumulus. There was one report of altostratus. The thin, streaky cloud elements between F and G are undoubtedly the upper cloud elements extending over the lower cloud field to the north.

The southeast sector of the anti-cyclone is covered by a field of cumuliform clouds. Unfortunately, the full extent of this cloud cover is not known due to the limits of the picture area, but it probably continues to the front in the central Pacific. The organization of these small cumulus clouds into rows is rather prominent in the area just southeast of F. This is an area of pronounced streamline divergence in the lower levels.

The vortex of the occluding system is shown on the mosaic between E and D. The post-frontal cloud distribution west of D is typical of that found behind an occlusion in the beginning stage of decay (Boucher and Newcomb, 1962). The center of the cloud spiral as shown in the photographs is displaced to the east of the analyzed isobaric center. Whether this relationship is rigorous or whether with adequate data one would find the cloud center and the pressure center coincident is problematic. The thorough mixing of the air precludes an analysis of the occlusion into the vortex.

Though the cloud shield immediately surrounding the vortex has grown appreciably in size from the previous day, there is a zone of clearing along the southeastern sector of the cyclone. This zone of clearing has moved around the storm in the previous two days and now become orientated virtually north-south along the cold front near D. A ring of partial clearing is found along the southern and western sectors near E. Ship reports indicate the cloud type in the vicinity of the vortex to be stratus and stratocumulus in lower layers, but the appearance of the cloud

shield in the photograph (brightness and character near E) leads one to infer the presence of middle and high clouds also.

It is interesting to note the increase in extent of the prefrontal cloud shield between C and D associated with this storm. Cloud character appears quite uniform throughout. The increase in areal extent of this shield in the previous 24 hours reflects the continued spreading of the warm air due to the sustained poleward flow on the east side of the low.

Data from the Japanese Islands indicate a jet stream extending over the top of the ridge just downstream. On the eastern side of the ridge a new maximum isotach area is formed at the confluence of the warm tropical and cold maritime air flow. The jet stream enters the photographic field of view over the zone of clearing northwest of point E. It continues around the vortex just to the south of the partial clearing which exists in the southern periphery of the cyclone. It then proceeds northward along the perimeter of the vortical cloud shield across the occlusion and almost perpendicular to it. The maximum isotach area of the jet stream is located to the south and east of the low center. The location of the jet stream over the ridge to the east is not in the field of the photographs, but upper air observations (see Fig. 15) reveal its extension into the Aleutian area.

Between C and A the satellite pictures show the post-frontal cloud cover associated with the cyclonic system that has now traversed the West Coast of the United States. The photographs, in fact, extend farther eastward than does the rectification, which stops at the coastline. On the photographs the cloud system associated with the cold front is barely evident east of A.

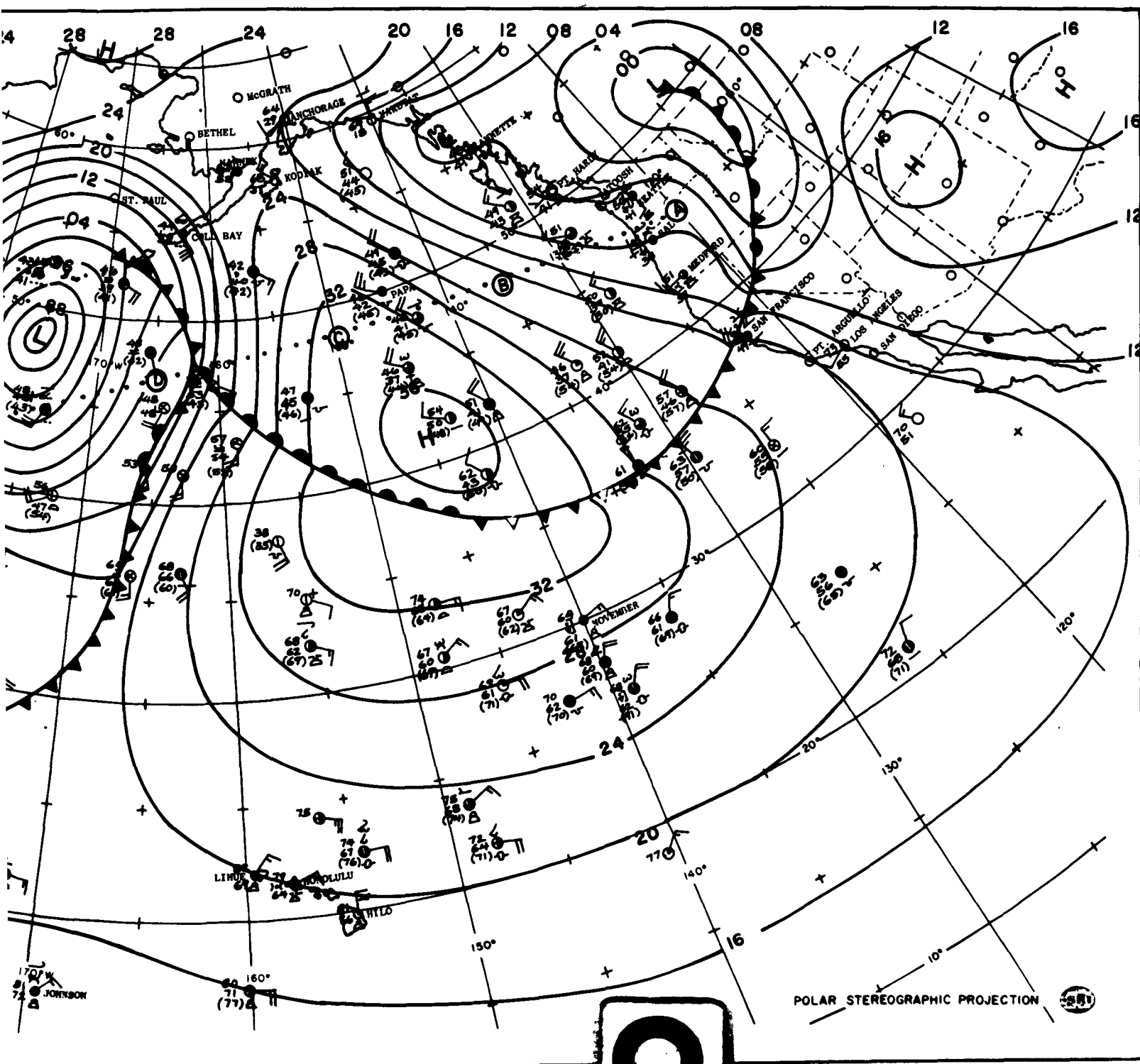
Several changes in cloud cover have taken place in the eastern Pacific in the past 24 hours. Small cellular convective cloud elements are still apparent in the post-frontal area between B and A, but a clear area has developed northwest of B and a large patch of bright clouds has appeared off the British Columbia coast.

In the eastern Pacific the cold low-pressure center aloft now lags far behind the surface center which is inland over the western United States.

The analysis of the surface pressure field immediately off the west coast indicates a predominant flow from the northwest. In the cloud photographs (just south of B) there is, however, an indication of a mesoscale cloud vortex which has no reflection in the surface isobars. Twenty-four hours later an intense, small vortex crossed the West Coast of the United States accompanied by showery and squally weather (Nagle and Serebreny, 1962). Here is further evidence of satellite cloud photographs indicating the existence of phenomena of considerable importance to forecasting along the West Coast of the United States that was not revealed by conventional observations.

The extensive deck of bright clouds north and east of the upper low-pressure center are a continuation of the prefrontal cloud shield which now extends almost completely around the upper-level cyclone. The influx of cold air in the upper levels is becoming cut off as this warm, tropical air advects around the upper air vortex.





14 SURFACE MAP, 21 MAY 1960, 0000 G.M.T.

FIG. 14

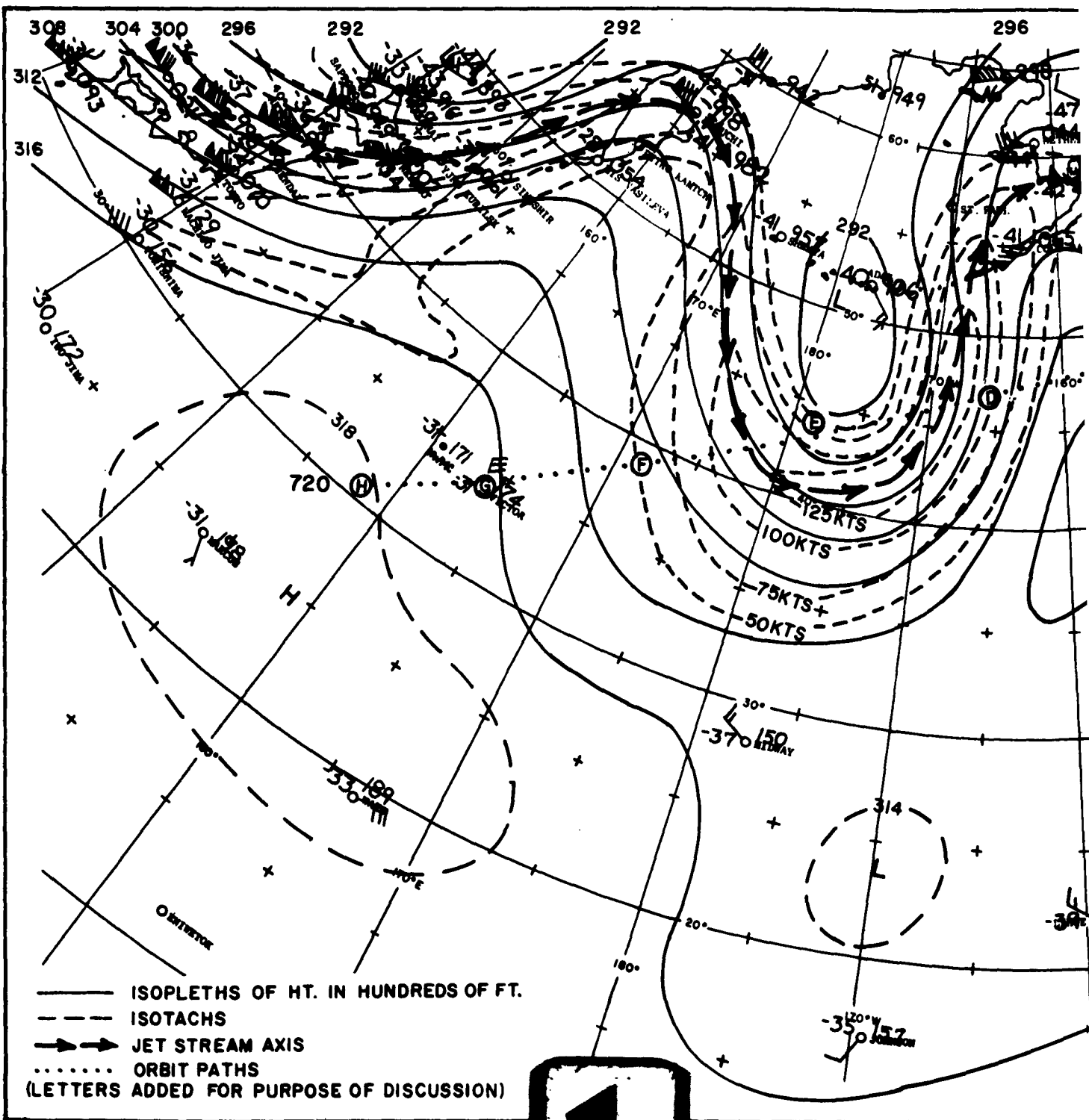


FIG. 15 300-mb MAP, 21 MAY 1964

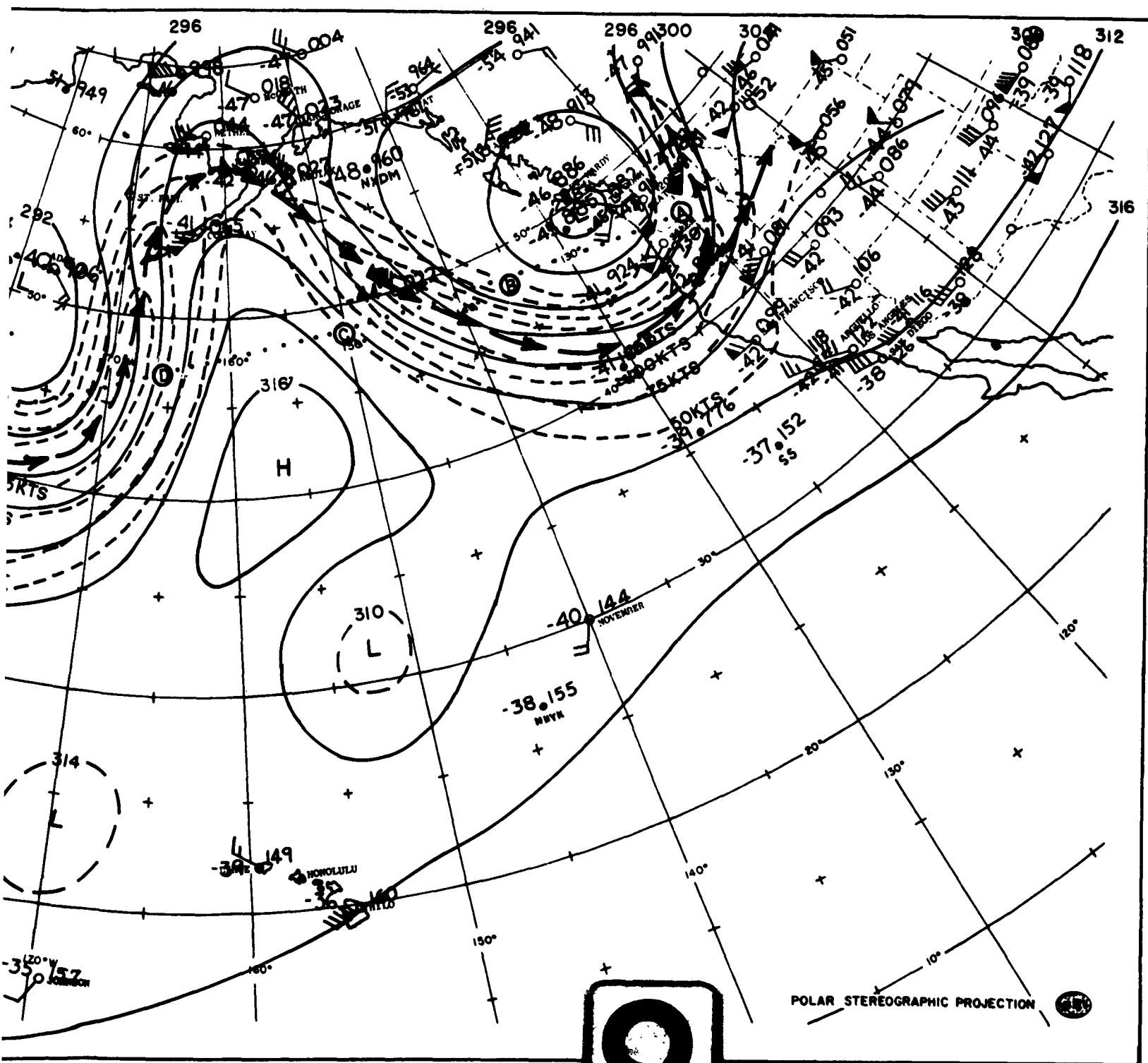


FIG. 15 300-mb MAP, 21 MAY 1960, 0000 G.M.T.

FIG. 15

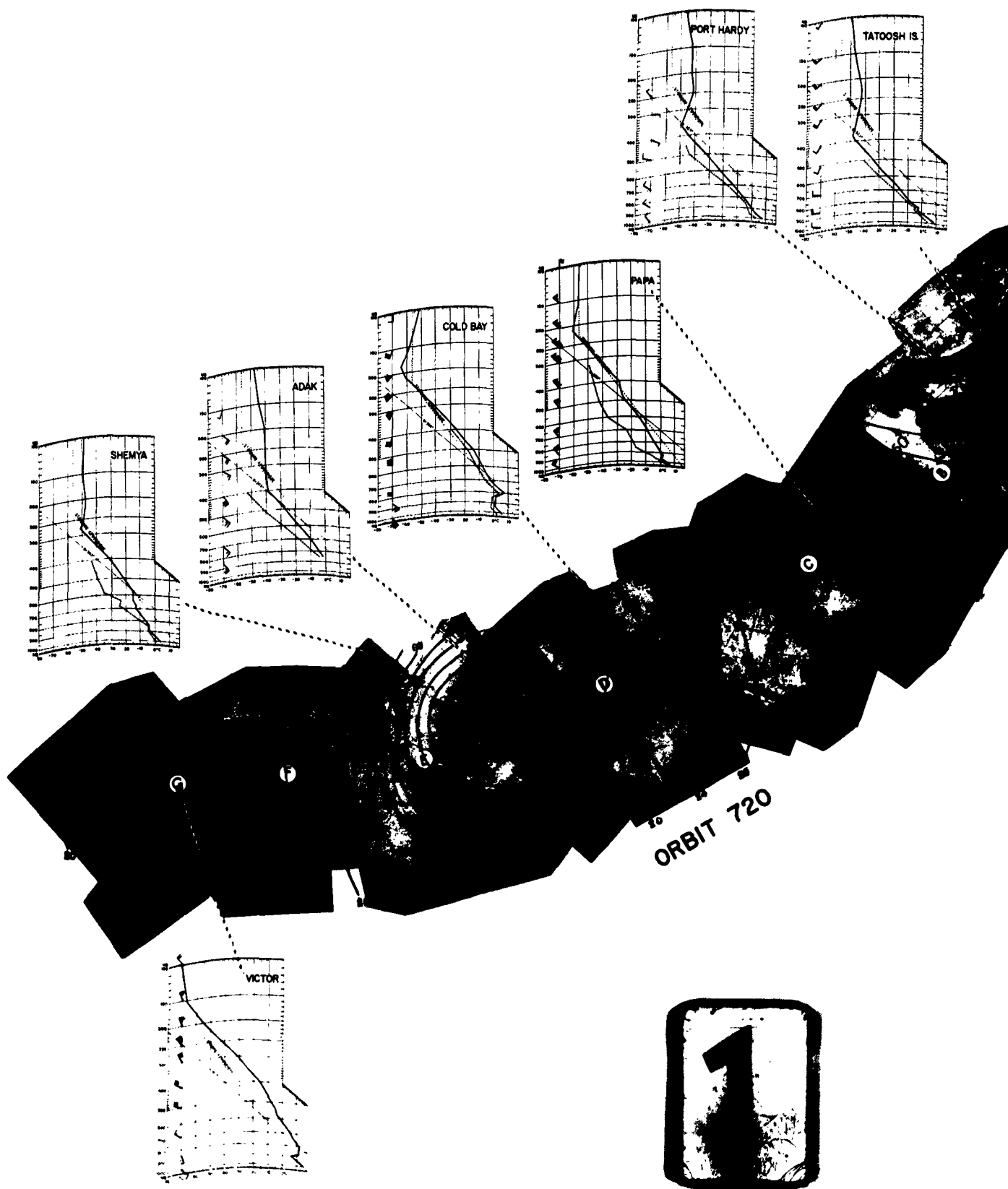


FIG.16 CLOUD MOSAICS WITH SURFACE PRESSURE SYSTEMS FOR 21 MAY 1960,0000 G.M.T.



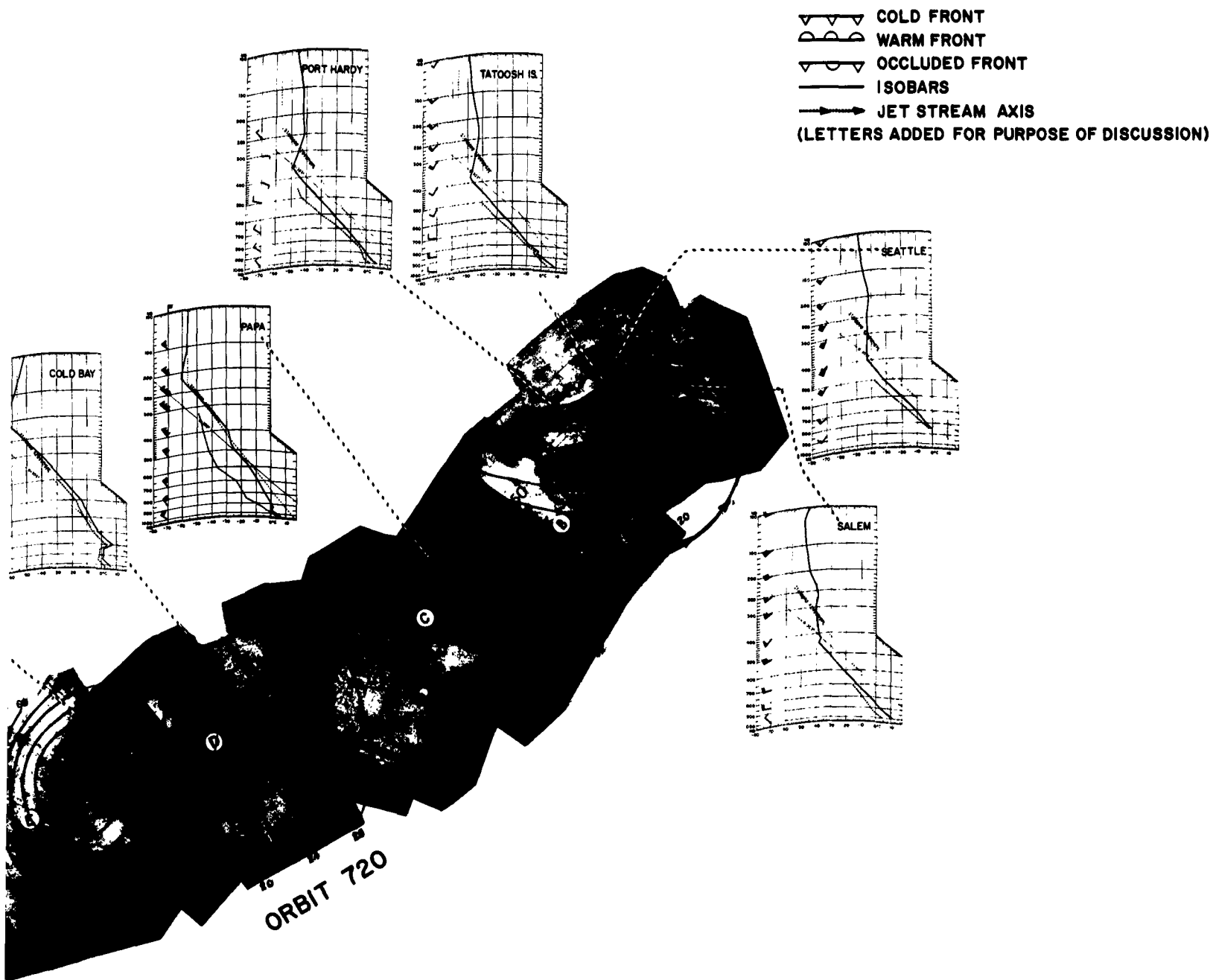
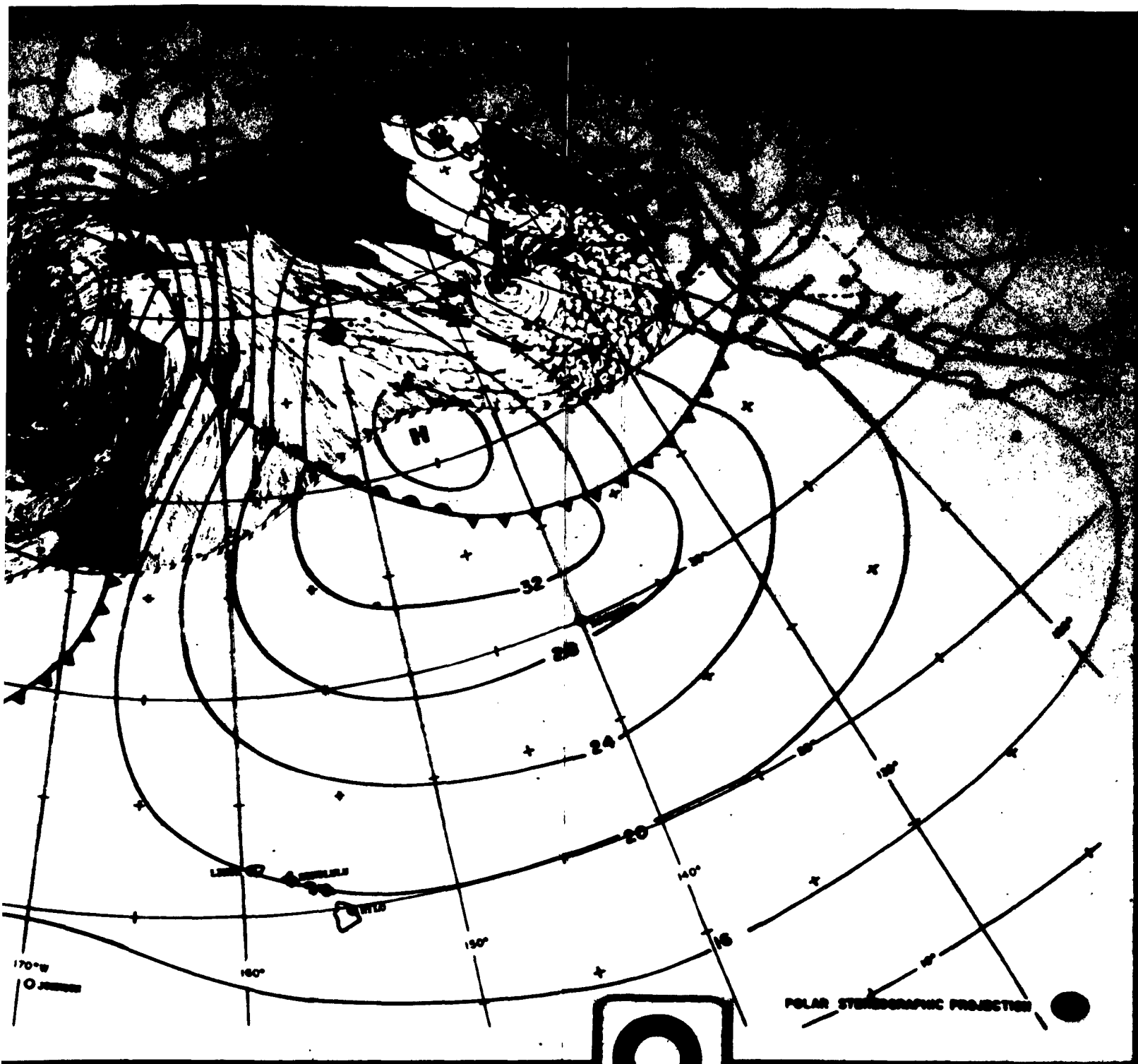




FIG. 17 RECTIFICATION OF CLOUD PHOTOGR



CATION OF CLOUD PHOTOGRAPHS, 21 MAY 1960, 0000 G.M.T.

FIG. 17

E. 22 May 1960

During the 24 hours previous to May 22nd, the meridional flow continued to be well developed (see Fig. 18). In the western Pacific the wave cyclone has moved some 600 miles northeastward. The low in the central Pacific has filled substantially, while moving northward. In the eastern Pacific the high-pressure cell has intensified and broadened slightly, with a strong ridge line extending due north to southern Alaska. A marked low-pressure trough has developed off Seattle, accompanied by the appearance of a secondary front. Air-mass contrasts at the surface are rather weak in this area, but a frontal formation in the deepening trough is suggested.

Aloft (Fig. 19) there is an extended ridge reaching into Alaska. The amplitude of the trough upstream, in the central Pacific, is diminishing while the trough downstream, off Seattle, is developing in intensity. In the lower latitudes a trough is evident west of the Hawaiian Islands with westerlies continuing as far east as Mexico.

The cloud pictures utilized on this date were taken from Orbits 731, 732, and 733, and were confined entirely to the eastern Pacific. The photo mosaic is shown in Fig. 20, and the rectification in Fig. 21.

#### Orbit 733

This orbit begins about 300 miles east of Midway and extends northeastward, crossing the coast of the United States over Seattle. It transits the cloud shield associated with the cold front (near E) at 35°N and 162°W, and passes over the Pacific anti-cyclone between D and C. East of this area it crosses over the deepening trough off the coast of Washington (near B).

On the mosaic (Fig. 20) the band of frontal clouds in the central Pacific, oriented north-south (between E and D), appears very bright and quite opaque. The post-frontal area includes a cloudless region adjacent to the frontal cloud band. Further north in the post-frontal cold air there is distinct cloud cover composed of relatively small cumuliform elements distributed over a wide area. From the eastern perimeter of the

frontal band to the ridge line downstream (see area D and C) the clouds are thin and fibrous in appearance, and may be high clouds embedded in poleward-moving warm tropical air.

Ships in the area reported overcast conditions with a considerable amount of fog. However, stations in southern Alaska and southeast of the high-pressure center with only partial low cloud cover, did report altostratus clouds, which probably extend over the entire area. A rift in the cloud cover extending north-northwest to south-southeast is noted, over OSV Papa. This rift is almost coincident with the analyzed position of the ridge aloft.

The jet stream in the western Pacific continues to be located along the ridge near the Aleutians with the maximum isotach area located on the apex of the ridge. With the filling of the low-pressure system in the central Pacific, the strong winds become discontinuous around the southern side of the upper trough, becoming reestablished on the east side of this trough at about 165°W long. Only a portion of the jet stream complex is contained in the cloud rectification and mosaic in this area. The clouds immediately beneath the jet stream are of a scattered cumuli-form nature, typical of post-frontal clouds in cold air.

The cloud pattern in the eastern Pacific shows a marked cyclonic curvature (see area surrounding B), which ends in a definite hook just south of B. This hook seems to be closely associated with the region of maximum cyclonic curvature in the surface isobars, but the over-all cloud pattern nearly follows the configuration of the 300-mb low as the warm air continues to be advected around the northern and western side of the cyclone. The over-all appearance of the cloud cover in area B is somewhat analogous to that reported by Fritz (1961) for a closed low-pressure system in the Atlantic.

Observations along the West Coast of North America definitely indicate the presence of a weak jet stream around the eastern and northern periphery of the upper-level cyclone. The jet stream seems to lie over a thin patch of clouds (see east of B) in this region of the system. A ship in the area of the cloud cover reports high and middle clouds.

According to Nagle and Serebreny (1962), a moist, maritime Polar cold-air mass had circulated north over the continent and curved offshore in this area.

The principal jet stream in the eastern Pacific lies over the clear area northwest of B and proceeds around the southern edge of the upper-level cyclonic circulation, passing to the southwest of the cyclonically curved cloud mass south of B.

#### Orbit 732

In the Pacific this orbit extends from Honolulu to Medford, Oregon, passing over the southeast portion of the Pacific anti-cyclone and the southern periphery of the upper-level cyclone off the Washington coast.

It is of interest to note that the bright, patchy-appearing clouds on the photographs (Fig. 20) south of D are the western edge of a cloud cover that extends westward from the California coast. Ships in the area report low clouds to be cumulus and stratocumulus with substantial amounts of middle clouds, mostly altocumulus associated with cumulus. This cloud cover is undoubtedly associated with the remnants of the weak cold front which seems to extend from the low-pressure center over southern Nevada around the base of the subtropical anti-cyclone into the warm front of the occluded cyclone in the central Pacific. An examination of the soundings at OSV Nan would reveal no distinct changes in air mass. However, analysis of the surface map shows a line of definite temperature contrast accompanying the implied frontal location. The orientation of the surface wind flow indicates that there is a very definite asymptote of streamline convergence in this area of extensive cloudiness, particularly along the southern periphery of the subtropical anti-cyclone.

Between C and A the satellite observations provide a view of the southern portion of the low-pressure area off Seattle. The cloud mass northeast of a line between C and B is bright in appearance, with few breaks. Reference to the surface map shows this area to lie to the west of a trough between B and C. Ship reports show a low overcast of stratus, with one ship reporting altostratus overcast between B and C. The brightness of the cloud mass would seem to indicate that an upper cloud deck

might extend over a substantial portion of this area. Southeast of B and C, the cloud elements become small and rather scattered. This could be expected in areas of pronounced streamline divergence. Ships in this area reported scattered cumulus or swelling cumulus (as the brightness of some of the scattered clouds on the photograph would imply) with no upper clouds present.

The jet stream lies around the base of the trough between B and C, passing over both the dense and scattered portions of clouds with no unique orientation or development in the cloud cover that could be attributed directly to the jet stream. It crosses the coast south of B. The area from B to A on the cloud photograph shows the cloud field over the mountainous area of the western United States with the prefrontal cloud shield evident east of A. This area is not included in the rectification.

#### Orbit 731

Orbit 731 extends southwestward from Lower California. It shows a limited segment of the extreme southeast sector of the eastern Pacific anti-cyclone shown in the previous orbit. The cloud cover appears bright and dense, and is arranged in broad, east-west-oriented bands.

The cloud cover between B and C is an extension of the broad cloud band seen south of D on Orbit 732, which has been previously mentioned as possibly being associated with a weak surface front. The apparently clear area northwest of A is a poor-quality view of the scattered cloud field south of B on Orbit 732.

In this area the subtropical jet stream, oriented east west, lies over the dense cloud field shown northeast of B on Orbit 731, and south of D on Orbit 732. No consideration was attempted, at this time, as to any possible interconnection between this cloud cover and the subtropical jet stream.





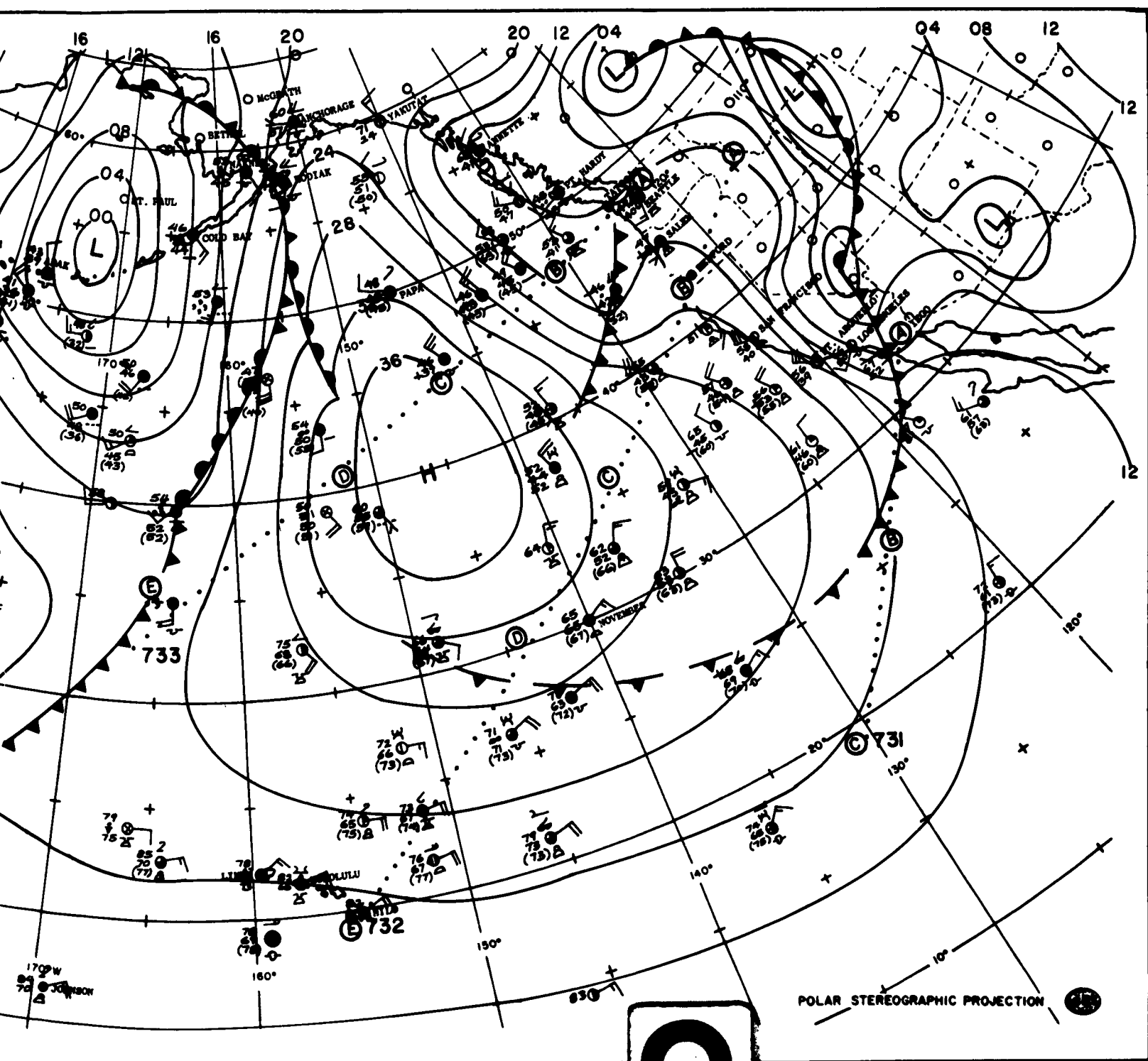


FIG. 18 SURFACE MAP, 22 MAY 1960, 0000 G.M.T.

FIG. 18

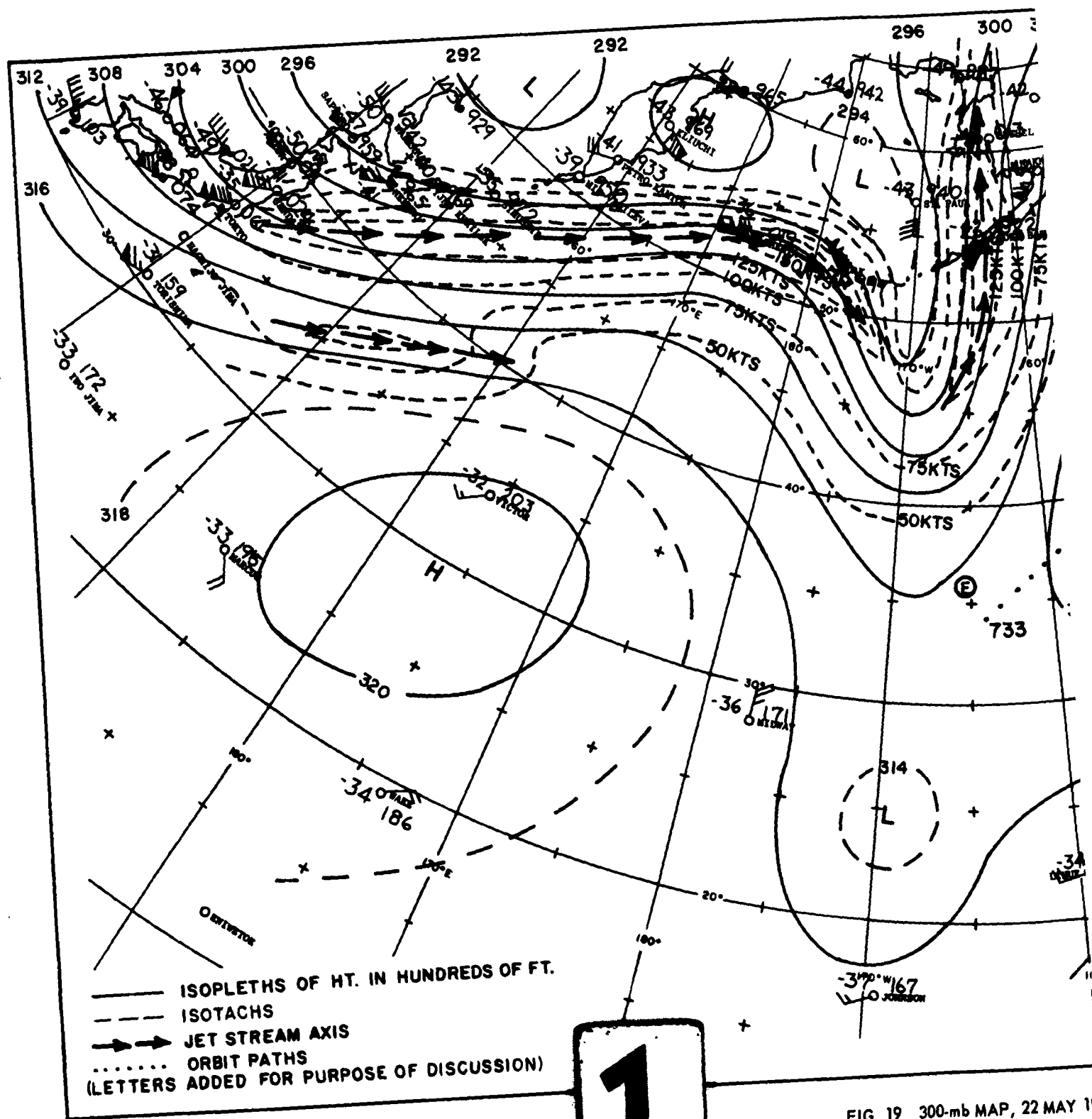
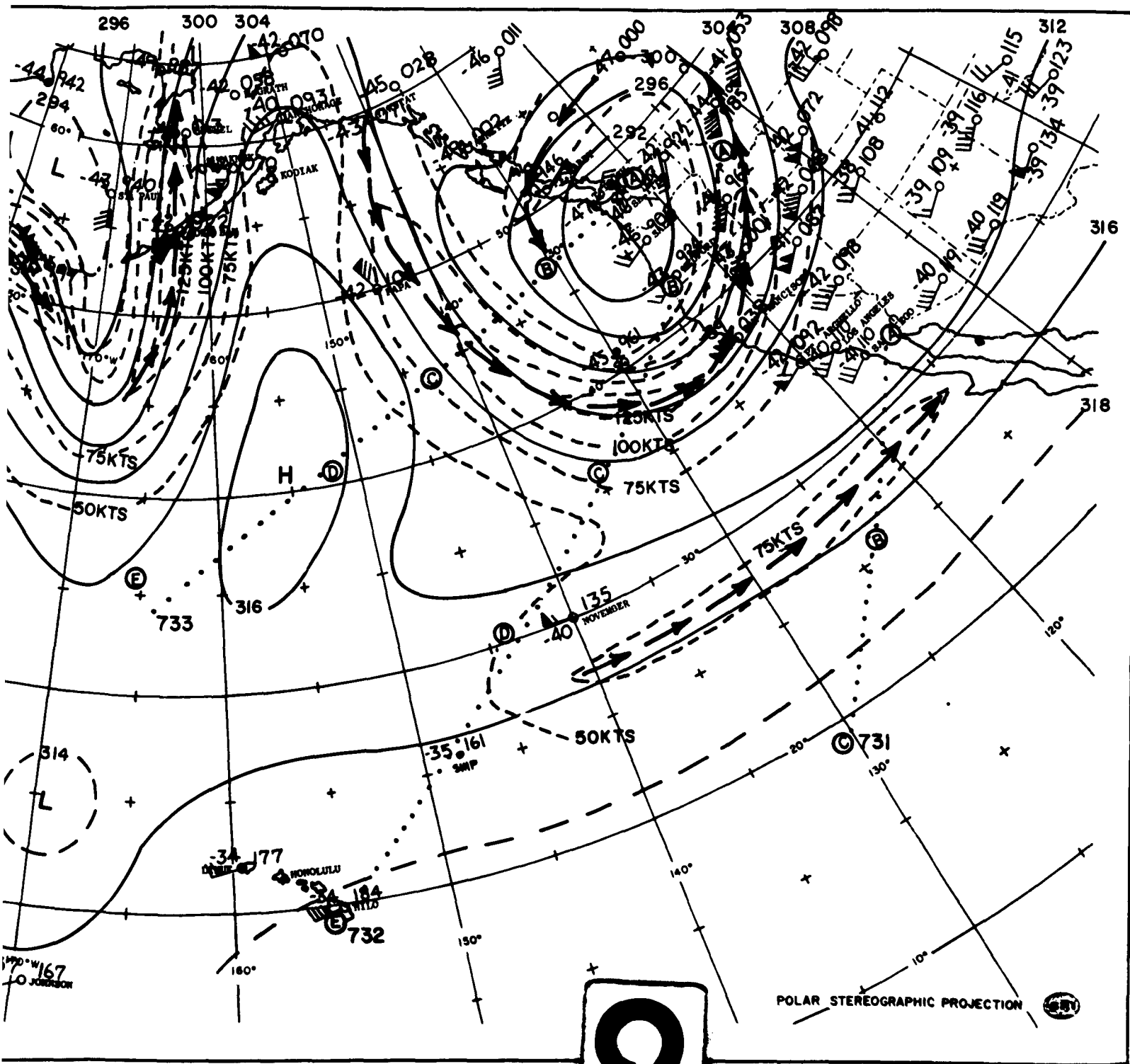


FIG. 19 300-mb MAP, 22 MAY 1967



G. 19 300-mb MAP, 22 MAY 1960, 0000 G.M.T.

FIG. 19

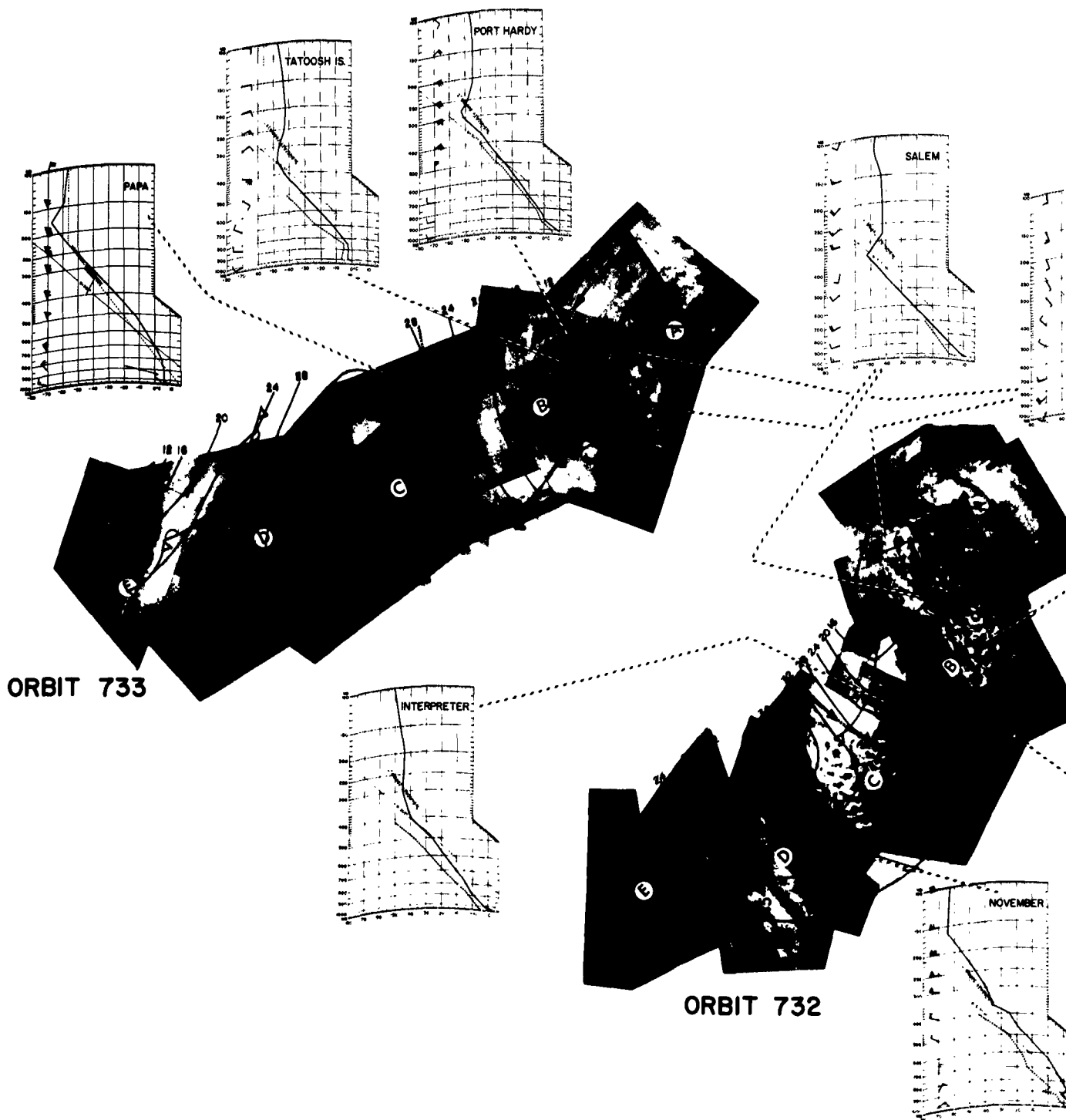
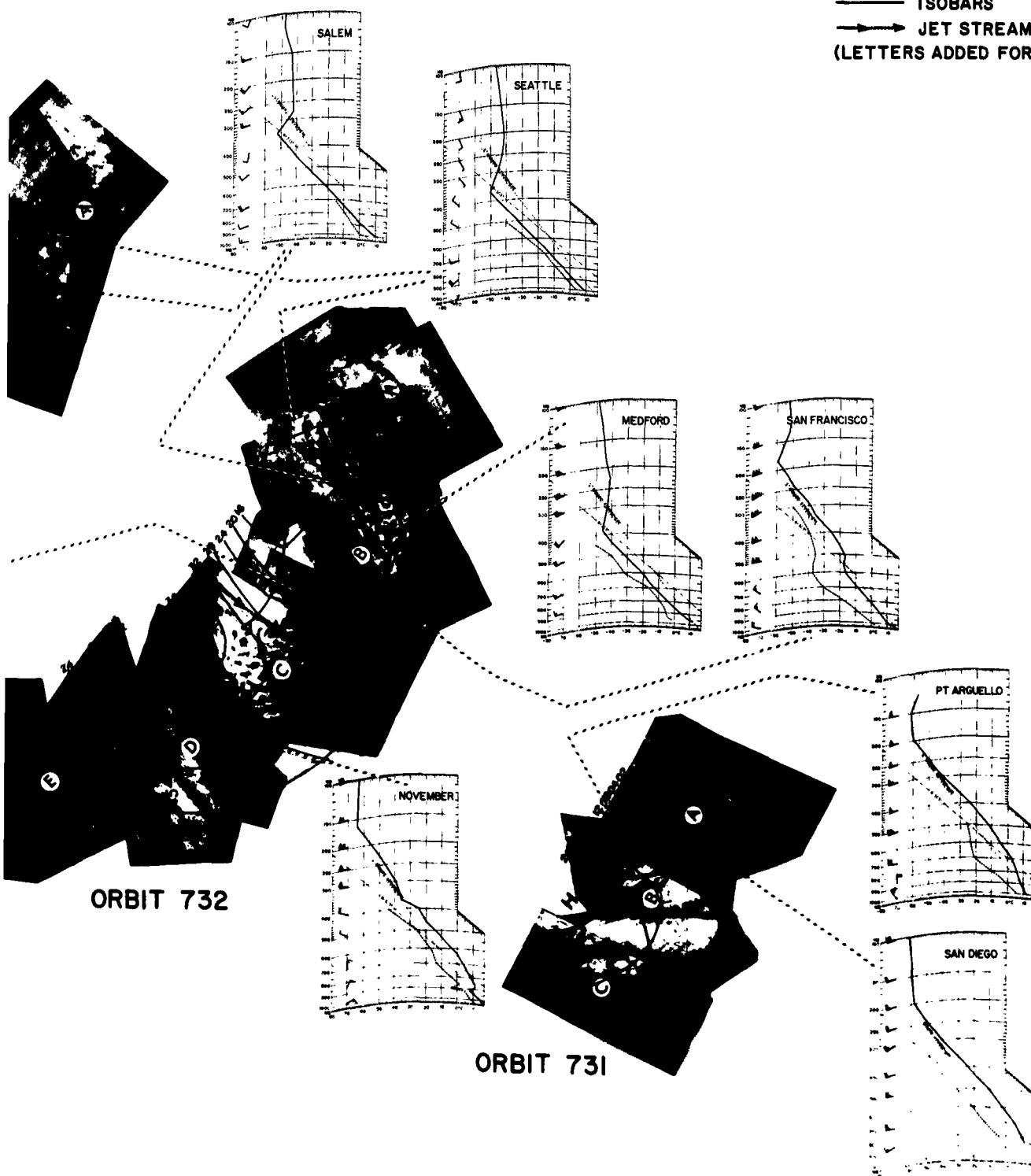


FIG. 20 CLOUD MOSAICS WITH SURFACE PRESSURE SYSTEMS FOR 22 MAY 19

- ▽▽▽ COLD FRONT
- ◡◡◡ WARM FRONT
- ▽◡▽ OCCLUDED FRONT
- ISOBARS
- JET STREAM AXIS
- (LETTERS ADDED FOR PURPOSE OF DISCUSSION)







F. 23 May 1962

Analysis of the surface data (Fig. 22) shows the continued eastward movement of the wave systems in the western Pacific, over the northern periphery of the subtropical anti-cyclone. The low-pressure area previously located in the central Pacific has moved due northward into the Bering Sea, and the principal occlusion continues to weaken along the elongated ridge and anti-cyclone in the eastern Pacific. In the previous 24 hours the developing trough along the west coast of Washington and British Columbia deepened to the extent of showing a closed circulation in the surface isobars. The secondary front is now offshore from San Francisco.

The upper-air map (Fig. 23) on this date shows the further development of the blocking high-pressure ridge into two cells, one over Alaska and the other near 40°N, 150°W. The trough upstream of this blocking high shows signs of weakening and becoming smaller in amplitude while the low-pressure area downstream off the California coast continues to deepen and broaden. The westerly flow is still in evidence in the subtropical latitudes of the central and eastern Pacific.

On this date the cloud pictures were taken from Orbits 746, 747, and 748, see Fig. 24. The rectification of these orbits is shown on Fig. 25.

Orbit 748

The track of this orbit starts about 500 miles north of Midway Island near the center of the subtropical anti-cyclone in that area, and runs northeastward to Seattle. The orbit crosses the principal front in the eastern Pacific between E and D, a ridge between D and C, and a developing trough in the area between C and A off the U.S. West Coast.

The mosaic for Orbit 748 shows an extensive clear area around F in association with the surface high-pressure system in the area. Extensive amorphous cloudiness can be seen to the north of this anti-cyclone associated with the frontal system in that area. Surface ships under this dense cloud field reported overcast conditions of low stratus, while ships just to the north of the picture area, in a few instances, reported



the presence of altostratus in addition to low clouds. This altostratus shield undoubtedly extends over a major portion of the cloud cover north of F and E. The clouds in the area of partial clearing southeast of F and southwest of E are reported as  $CL_4$  (stratocumulus formed from the spreading out of cumulus).

Data from the Japanese Islands and western Aleutians indicate the existence of a strong wind field over the ridge in the western and central Pacific. Unfortunately, the area of picture coverage is such that only the eastern edge of this jet-stream region is seen where it approaches the trough north of E. It crosses above the surface front near its point of occlusion.

A second jet stream extending over a cloud field north of F in the photographs is shown on the 300-mb map some 500 miles farther south. Both of these jet streams terminate on the western side of the upper trough. The trough line itself overlies a partial clearing on a north-south line in the cloud field (see north of E).

A strong isotach field is reestablished on the eastern side of the trough aloft (above D), and extends northward over the Alaskan Peninsula. The cloud pictures cover only a portion of the entrance region of the southern extremity of the maximum isotach area. The jet stream is located just west of the dense frontal cloud band shown on the mosaic west of D. This cloud band has a decided north-south orientation, with the majority of cloudiness lying behind the cold front.

East of this front, between D and C, the cloud field is less opaque and quite patchy in character. The general impression of this cloud field is also one of north-south banding, which is indicative of strong meridional flow. The analysis indicates that, with the establishment of the block, warm tropical air is being thrust northward to high latitudes. Although ship reports in the area show both high- and low-level cloud types, this banding is probably primarily associated with upper clouds in the advecting tropical air.

One of the most striking features in the cloud distribution on this date is the extensive clear area (shown between C and B) that extends

from the Gulf of Alaska to about the 40th parallel. During the previous 24 hours this clear area increased in size considerably from a wedge of clear air located solely within the Gulf of Alaska, to an area whose length is some 1200 miles. This clearing occurs concomitantly with the maximum meridional penetration of the upper-air ridge into Alaska. With establishment of the block in Interior Alaska, dry Arctic air is being advected southward along the eastern side of the ridge, abetted by a substantial amount of subsidence due to the high-pressure system itself.

Such clear areas on the east side of intense ridges may be characteristic in the development of these blocking high-pressure areas. (It is interesting to note that at no time during this sequence were clear skies reported at OSV Papa, indicating that the advecting dry Arctic air never reached the station.) Oddly enough, ships in the area east of OSV Papa were by coincidence so spaced that each ship reported cloud cover--a fact which would undoubtedly lead an analyst to assume such cloud cover prevalent over the entire area. The satellite shows a clear area in excess of 200,000 square miles embedded between the ships. This situation clearly brings out the risk of assuming a cloud-cover continuum in an area of sparse data, and the intrinsic advantage of cloud photographs from satellites for many operational purposes.

The jet stream in the eastern Pacific is intensified on the east side of the ridge just over the clear area between C and B, extending over this clear area as far south as the 40th parallel.

Between B and A the photographs show the northern periphery of the cloud system accompanying the vortex off the Washington coast. At this time the surface and upper-air low-pressure areas are nearly coincident. Maritime polar air aloft almost completely encircles and overrides the cold air in the surface system, the center of which is almost free of clouds.

A secondary jet stream which has accompanied the advection of warm maritime polar air around the low-pressure circulation aloft has progressed to the western side of the cyclone over B. In this region this jet stream lies over the large, opaque cloud mass to the west of the

disturbance. Surface reports indicate low, middle, and high clouds over the region.

#### Orbit 747

The track of this orbit lies between Midway and the Hawaiian Islands and extends to Seattle. It passes over a cold front in the low latitudes between E and D, the eastern Pacific high cell near C, and the developing trough area off the Washington coast.

By virtue of the satellite's trajectory, the camera scans most of the cloud systems photographed in Orbit 748, just described. Between E and D the cloud system is associated with the low-latitude portion of the principal frontal system in the east central Pacific. The photograph of what appears to be a small clear area to the northwest of E is a high nadir-angle view of the clear area in the high-pressure cell shown at F on Orbit 748. The clouds north of B and C of Orbit 747 are those of the cloud system in the ridge shown east of D on Orbit 748. The southern sector of the high-pressure cell between C and D on Orbit 747 is rather free of cloud. A ship in this area, however, reported some cirrus present. Between C and A may be seen more of the cloud cover visible in that region in Orbit 748, though from a somewhat lower latitude. The southern portion of the cloud field associated with the vortex off the Washington coast is now visible, and the more southerly portion of the interior of the vortex is seen to be covered by small cloud elements arranged in streets, similar in character to the clouds that covered the entire eastern Pacific some 48 hours earlier.

#### Orbit 746

The track of this orbit passes about 250 miles south of OSV November and just north of San Francisco. It passes over the southeast sector of the eastern Pacific anti-cyclone between C and B, and over a weak frontal area near A.

Between C and B, a broad banding of cumuliform clouds is visible that was noted earlier in the south-east sector of the subtropical anti-cyclone. This very bright, patchy cloud mass lies over an area where

surface ships reported swelling cumulus and cumulonimbus. Southeast of B and A there seems to be a distinct clearing in the cloud field where the wind directions imply pronounced divergence in the flow, indicating strong subsidence.

The principal jet stream that overlies the clear area west of the low on Orbits 747 and 748 is shown to continue around the south side of this vortex, over the region of clearing seen between B and A. The secondary jet stream, which lies over the cloud fields on the western side of the vortex in the aforementioned orbits, disappears at the trough line just north of A.



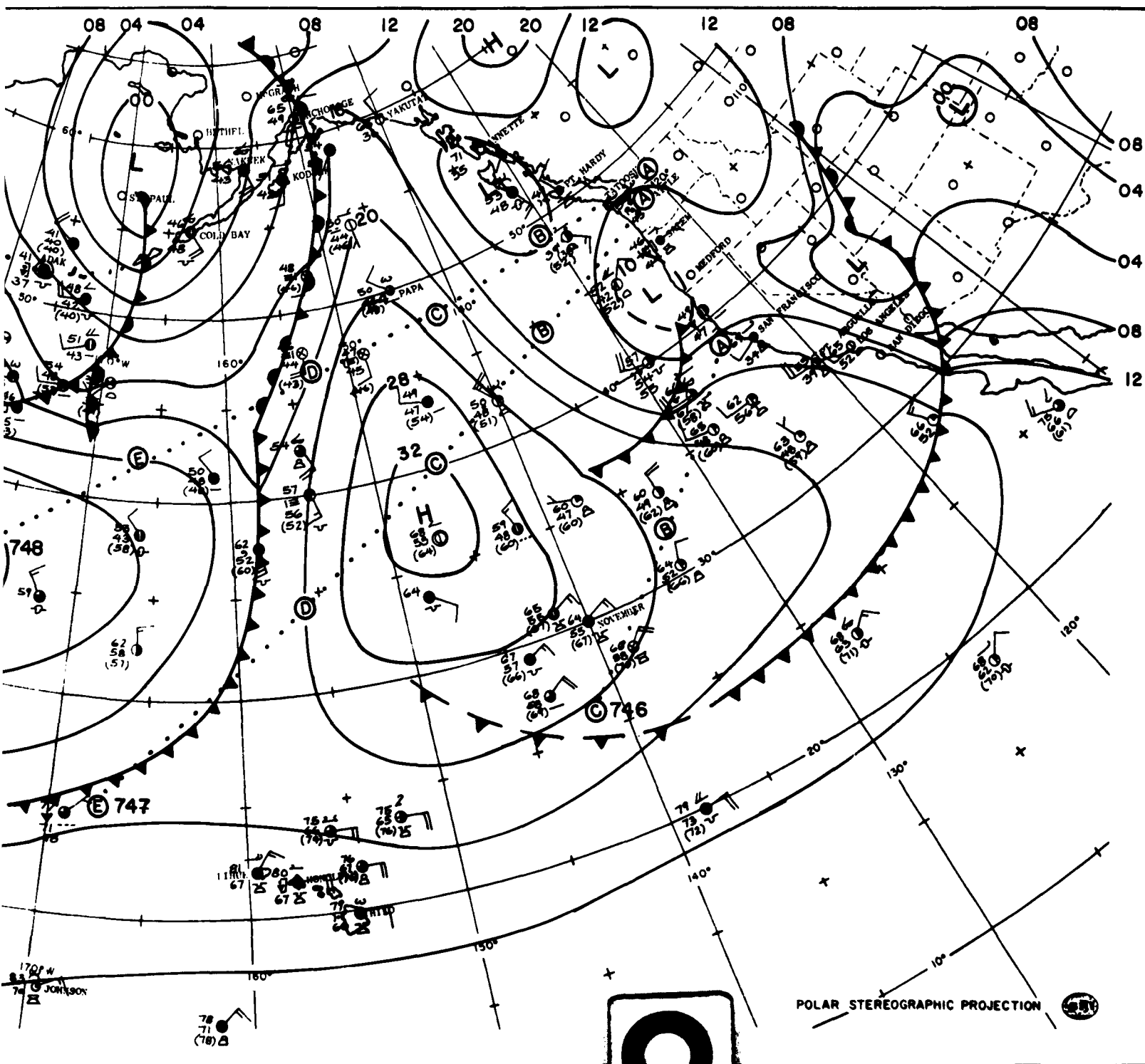


FIG. 22 SURFACE MAP, 23 MAY 1960, 0000 G.M.T.

FIG. 22



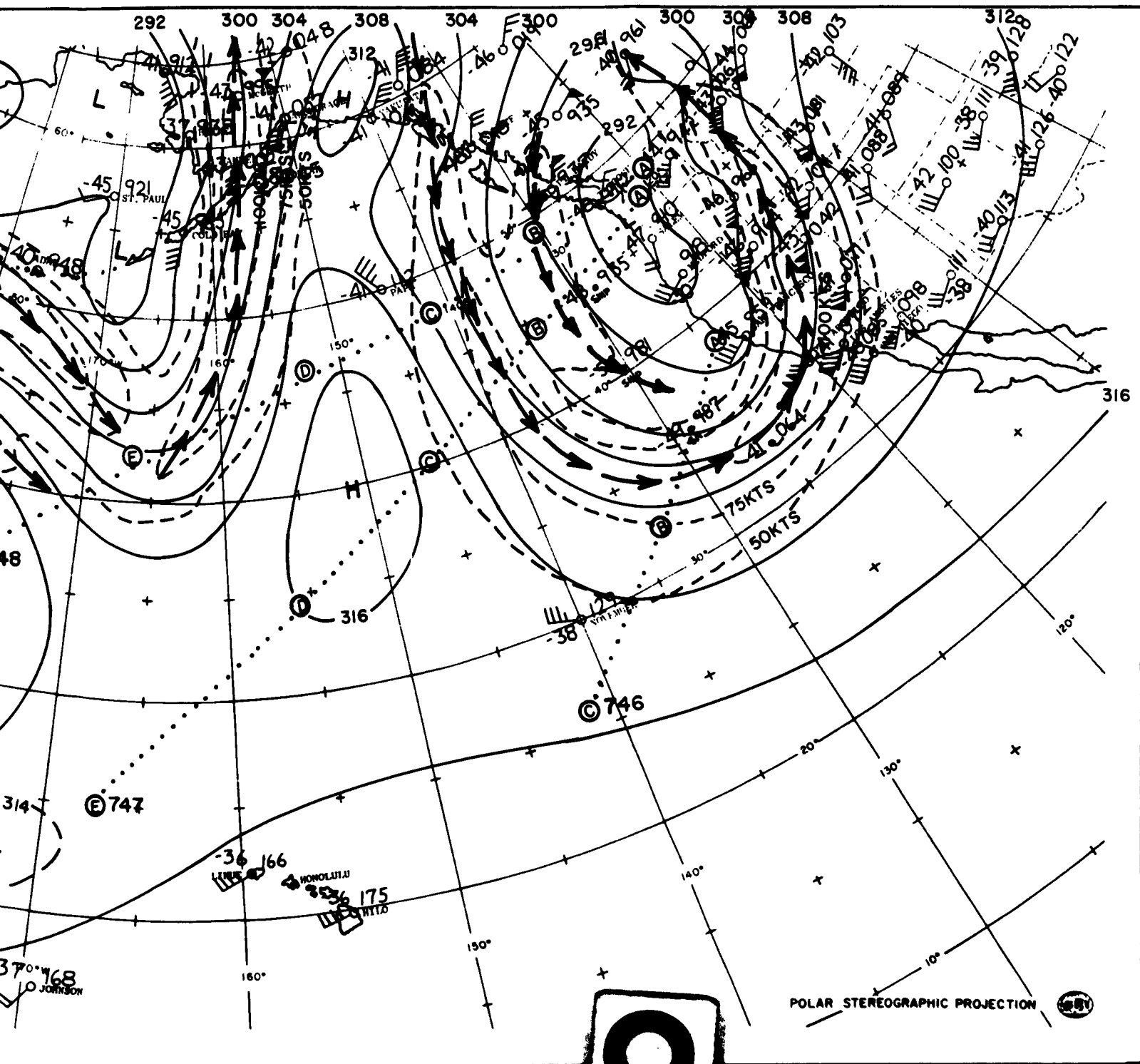


FIG. 23 300-mb MAP, 23 MAY 1960, 0000 G.M.T.

FIG. 23



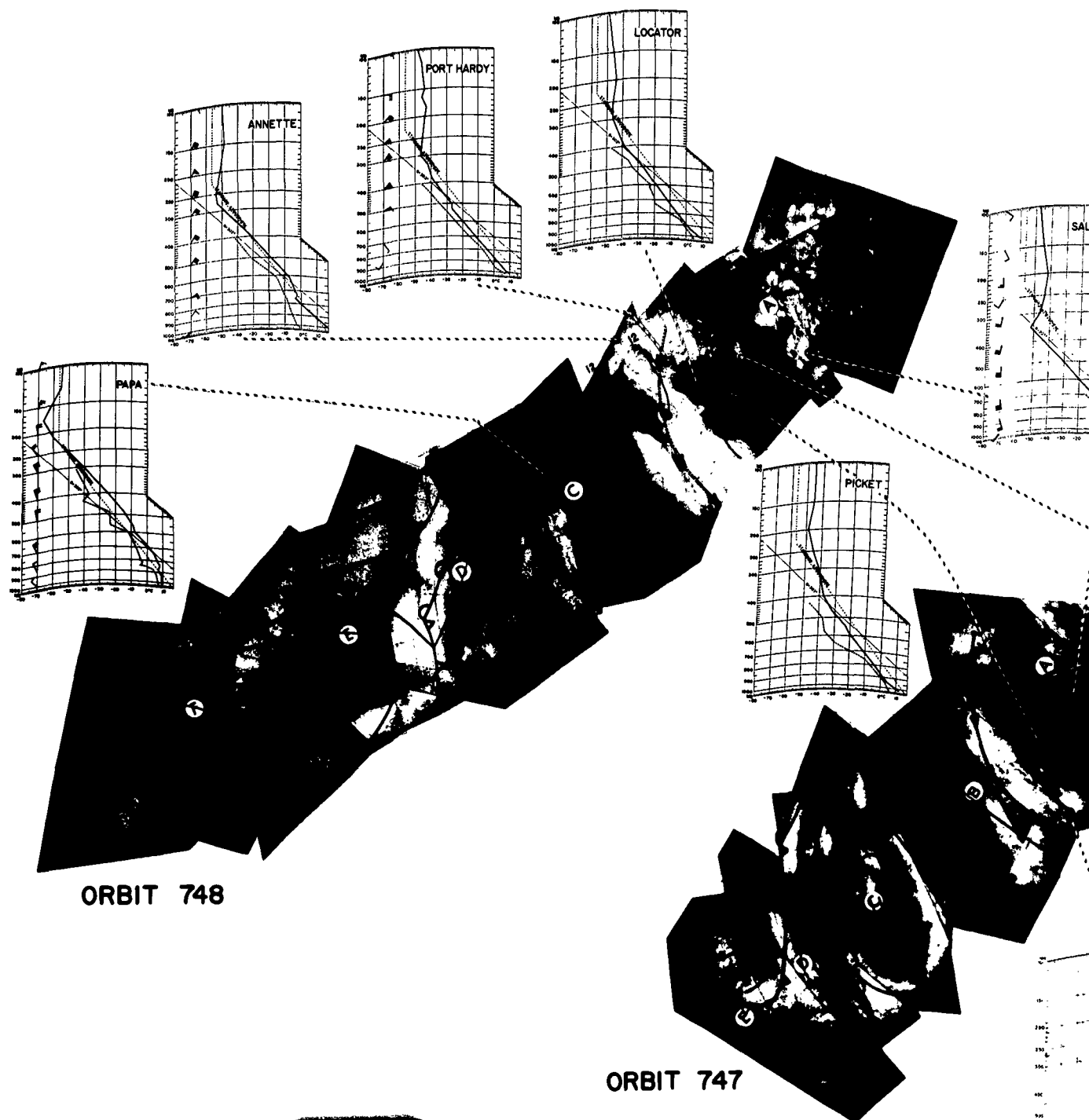
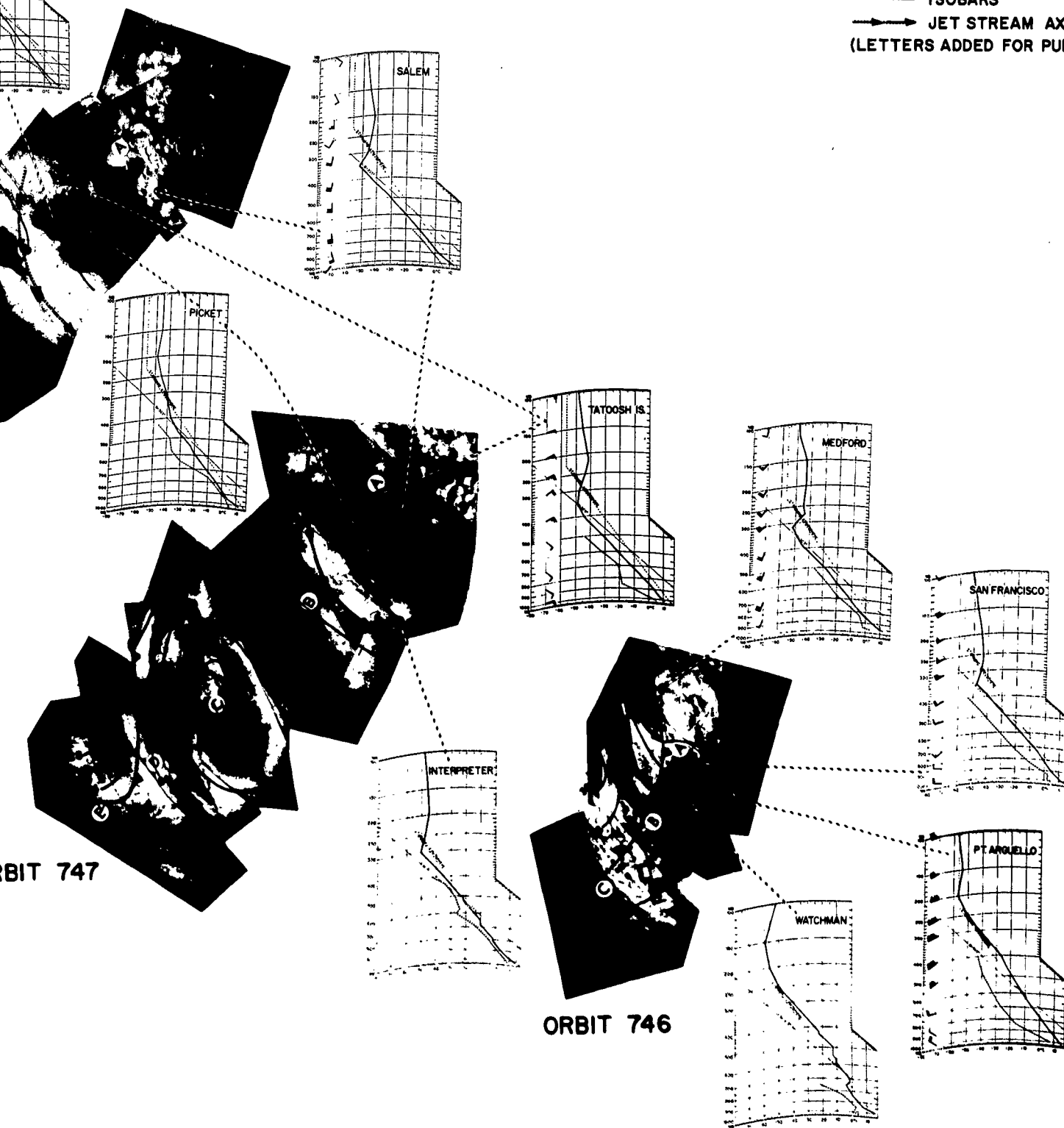


FIG.24 CLOUD MOSAICS WITH SURFACE PRESSURE SYSTEMS FOR



∇∇∇ COLD FRONT  
 ∪∪∪ WARM FRONT  
 ∇∪∇ OCCLUDED FRONT  
 — ISOBARS  
 → JET STREAM AXIS  
 (LETTERS ADDED FOR PURPOSE OF DISCUSSION)



CHARTS WITH SURFACE PRESSURE SYSTEMS FOR 23 MAY 1960, 0000 G.M.T.

FIG.24

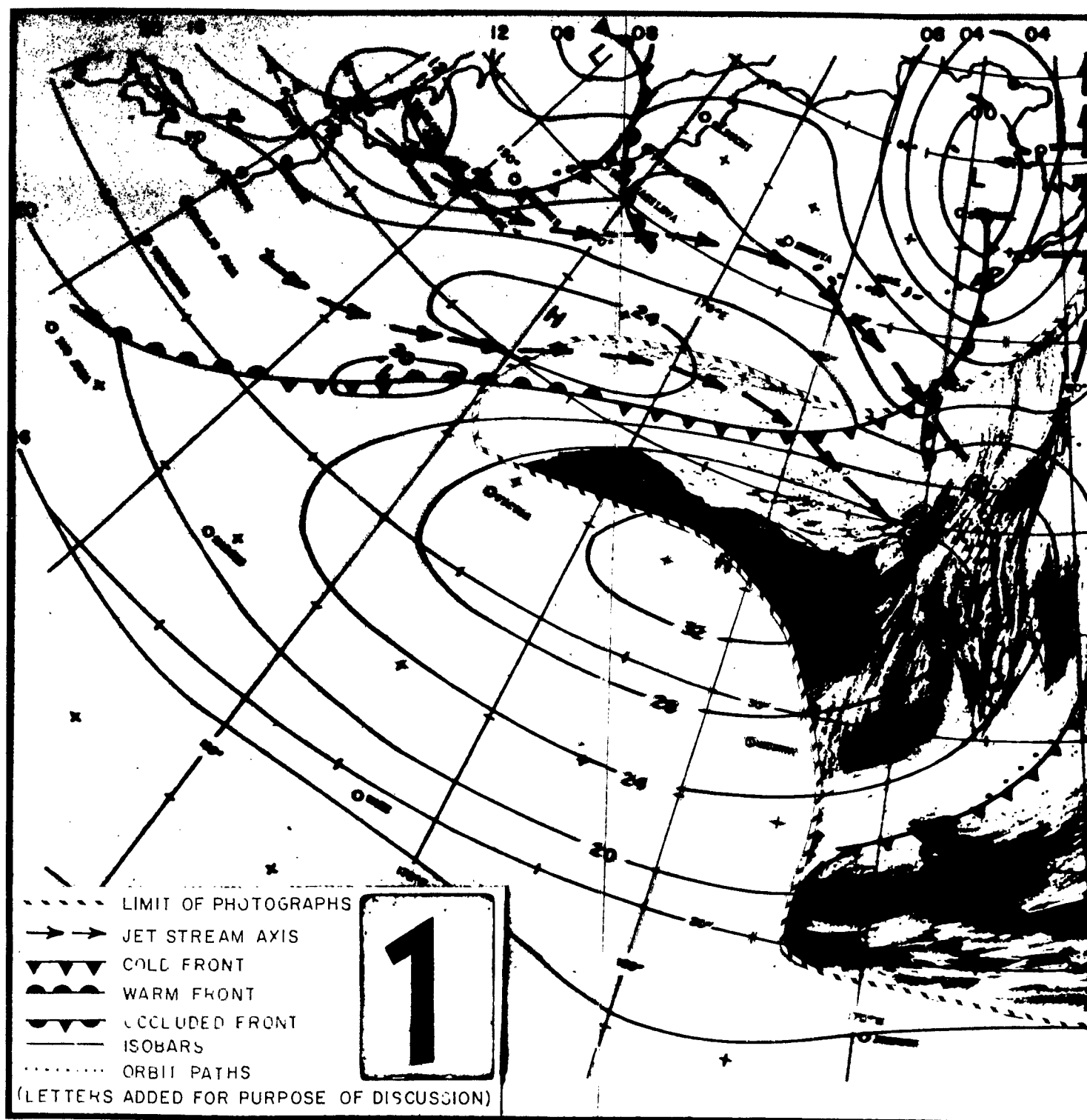
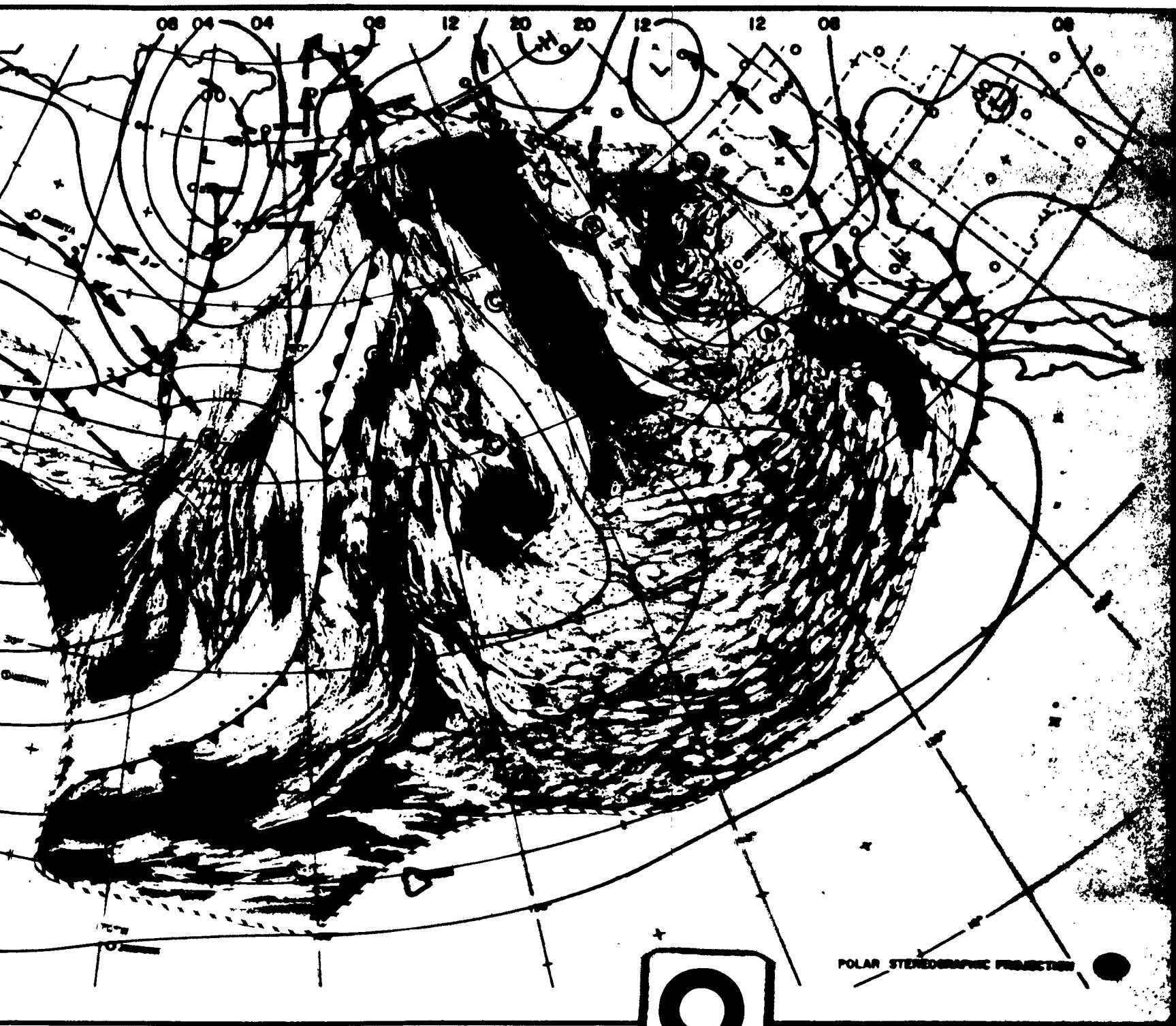


FIG. 25 RECTIFICATION OF CLOUD PHOTOGRA



RECTIFICATION OF CLOUD PHOTOGRAPHS, 23 MAY 1960, 0000 G.M.T.

FIG. 25

G. 24 May 1960

The surface map for May 24th (Fig. 26) indicates continued eastward progression of the wave families in the western Pacific. The cyclone near Kamchatka is now occluded, while the disturbance to the east is now a well developed open wave near  $45^{\circ}\text{N}$ ,  $177^{\circ}\text{E}$ . The eastern portion of this wave has been swept into the circulation of the main cyclone vortex now centered near Naknek, Alaska.

The remnant of the heretofore dominant surface front is still detectable in the analysis, appearing as a north-south-orientated cold front separating the subtropical anti-cyclones. In the eastern Pacific the high-pressure cell has weakened somewhat with a small anti-cyclonic circulation present off Annette Island. The cyclone off the west coast continues to deepen and move southward, with a definite trough in the isobaric pattern extending to the south-southwest.

The 300-mb chart (Fig. 27) still retains a cut-off high-pressure cell in the Alaskan area. The high-pressure ridge in the middle latitudes of the east-central Pacific which extended as far north as Alaska on the previous day, has virtually disappeared and given way to the reestablishment of zonal, westerly flow which converges with the northerlies off the Washington coast. Westerlies still prevail in the subtropical latitudes in the eastern and central Pacific.

The cloud pictures on this date were taken from Orbits 761, 762, and 763 (Fig. 28). The rectification of these orbits are shown in Fig. 29.

Orbit 763

In the Western Pacific, Orbit 763 lies along a line that extends from near OSV Victor through Salem, Oregon. Its track is quite close to Orbit 677 on the 18th of May and Orbit 720 on the 20th of May. The orbit passes over the developing frontal wave near G, transits post-cold-frontal weather between F and D, and crosses an occlusion just west of D. Between D and C it passes over the weakening cold front, while further to the east, between C and A, it passes over the northern portion of the low-pressure area just off the Washington-Oregon coast.

In the mosaic of cloud photographs the band of clouds extending over G is associated with the wave system in this region. A ship about 30 miles north of wave crest reported scattered cumulus and altostratus. North of the wave the clouds present a thin and banded appearance. This particular cloud photograph has been used by Boucher and Newcomb (1962) as a typical example of cloud patterning in incipient-wave cyclone formation. Immediately north of these clouds a marked clear area (northwest of F) associated with a sharp surface ridge is visible. Further to the north of this clear area (near the limit of the picture) there is a region of fairly dense clouds which is associated with the occluded cyclone off Japan. Because of the high nadir angle of the satellite camera the character of these clouds is not clearly apparent, but ship reports from the area indicate that fog, stratus, and rain predominate (particularly near the front). One ship reported altocumulus, and from the opaqueness of the cloud cover it is probably reasonable to assume that middle clouds are present over the entire prefrontal cloud shield, although it is recognized that the low angle of view contributes to this appearance.

Reference to the 300-mb chart shows that dual jet streams continue to extend over the western Pacific. The northernmost jet stream lies over the southernmost portion of the extensive prefrontal cloud shield accompanying the occlusion off Japan (see Fig. 28) with the maximum isotach area being positioned over the center of the 300-mb ridge. A second jet stream is present about 10 degrees farther south, almost overhead of the developing wave system between G and F. Here the maximum isotach area is located upstream from the wave.

Between F and D the post-frontal cloud cover west of the occlusion, though extensive, presents a rather patchy appearance. Ships in the area reported the low clouds to be stratocumulus, cumulus, and stratus, with the cumuliforms predominating. Further, the analysis shows that northwest flow predominates in this post-frontal area. Although low-level divergence is occurring in this area, the warming of this cold air from the surface below is evidently sufficient to retain the patchy cumuliform

cloud cover. One ship at E also reported altocumulus, which may or may not extend over a substantial portion of this area since most of the low cover is reported as broken or overcast, restricting the view of middle cloudiness.

In the upper air the trough associated with the front is filling. The jet stream weakens on the west side of this trough, reforming again in strength on the east side. The maximum isotach area on the east side of the trough is located out of the region visible from the satellite.

Although the surface front at D has been progressively weakening over the past few days, the cloud cover demarking the prefrontal cloud shield is still evident. Ships in this prefrontal area reported an overcast of altocumulus, and the fibrous structure of the cloud deck is certainly suggestive of the presence of cirrus as well.

East of the prefrontal cloud shield between D and C, and particularly from C to OSV Papa, the cloud cover is arranged in north-south streaks having a thin and filmy appearance. This cloud field lies over the region that contained a distinctly clear area 24 hours earlier. The filling-in of this area with clouds within 24 hours has been discussed by Nagle and Serebreny (1962). They attributed the disappearance of the clear area to the merger of the counterclockwise rotating and expanding spiral band of clouds associated with the vortex off the Washington coast, and with the advancing cloud cover from the west. The thin area of clearing just west of C is all that remains of this once broad, clear area.

The spiral cloud band that is associated with the vortex off the coast can be seen at the bottom edge of the mosaic below C and B. The cloud elements within the vortex between B and C are small in size and widely separated. Surface ships in this area report these clouds as cumulus and swelling cumulus. The increase in size of the clear area within the vortex (between C and B), from that of the previous day, can be attributed to increased subsidence within the Arctic air mass as the vortex retrogrades slightly.

Jet-stream analysis at the 300-mb level shows a maximum isotach area on the east side of the blocking high-pressure area, ending in the Gulf of Alaska. Further to the south an entrance region has developed where the westerlies that have reformed south of OSV Papa converge with the northerlies around the vortex. The center of the principal jet stream still appears to lie over the narrow remains of the clear slot seen west of C. The secondary jet stream, associated with the inner recirculation of warm maritime air around the vortex, is located along the inside edge of the spiral cloud mass seen at the bottom of the mosaic between C and B.

The cloud cover over A lies over land and is not shown on the rectification.

#### Orbit 762

The track of this orbit begins just west of Midway Island and extends northeastward to Tatoosh Island, Washington. In the Central Pacific it crosses the southeastern portion of a subtropical anti-cyclone (see G to F). It then crosses a weak cold front (between F and E), the two fronts in the eastern Pacific, and reaches the coast over the northern periphery of the vortex off the Washington-Oregon coast.

Although the nadir angle is quite high in the subtropical latitudes, the cumuliform character of the clouds in this area (near G) is quite apparent. Ship reports confirmed these clouds to be largely cumulus and stratocumulus, with one report of scattered cirrus. The center of the anti-cyclone at F is relatively clear.

Because of the convergent tracks of Orbits 763 and 762, the field of view for the remainder of the orbit east of E is essentially the same as that east of F on Orbit 763 (see Fig. 28). Despite the 90-minute difference in orbit times, the cloud photographs show no significant broad-scale change in character or distribution and, hence, the description given for Orbit 763 is applicable to the rest of this orbit.

#### Orbit 761

In the eastern Pacific the track of this orbit begins about 600 miles west of OSV November and passes over Salem, Oregon. The orbital



track lies to the north of the center of the subtropical high-pressure cell in the eastern Pacific (see south of D) and through the low-pressure area off the Washington-Oregon coast (see C to A).

The nadir angles for this series of pictures are all relatively large, resulting in a compressed appearance of the mosaic. The clear area seen south of D is associated with the subtropical anti-cyclone at the surface in the eastern Pacific. Just west of C the elongated clear area is an extension of the narrow and elongated clear slot seen just west of C on Orbits 762 and 763. A full view of the vortex off the Washington-Oregon coast is shown between C and A. Surface ships reported primarily swelling cumulus clouds in the area south of B, as the texture of the clouds in the photographs might suggest.

The principal jet stream extends southward over the clear area just west and south of C. The isotach maximum (Fig. 27) south and east of the vortex unfortunately is outside the limits of the mosaic. The secondary jet stream, as analyzed, is positioned over the opaque cloud mass east of C and parallel to it as far as the coastline (which lies under B). Although the subtropical jet stream is indicated on the upper-air chart, it is located out of the area of photo coverage.





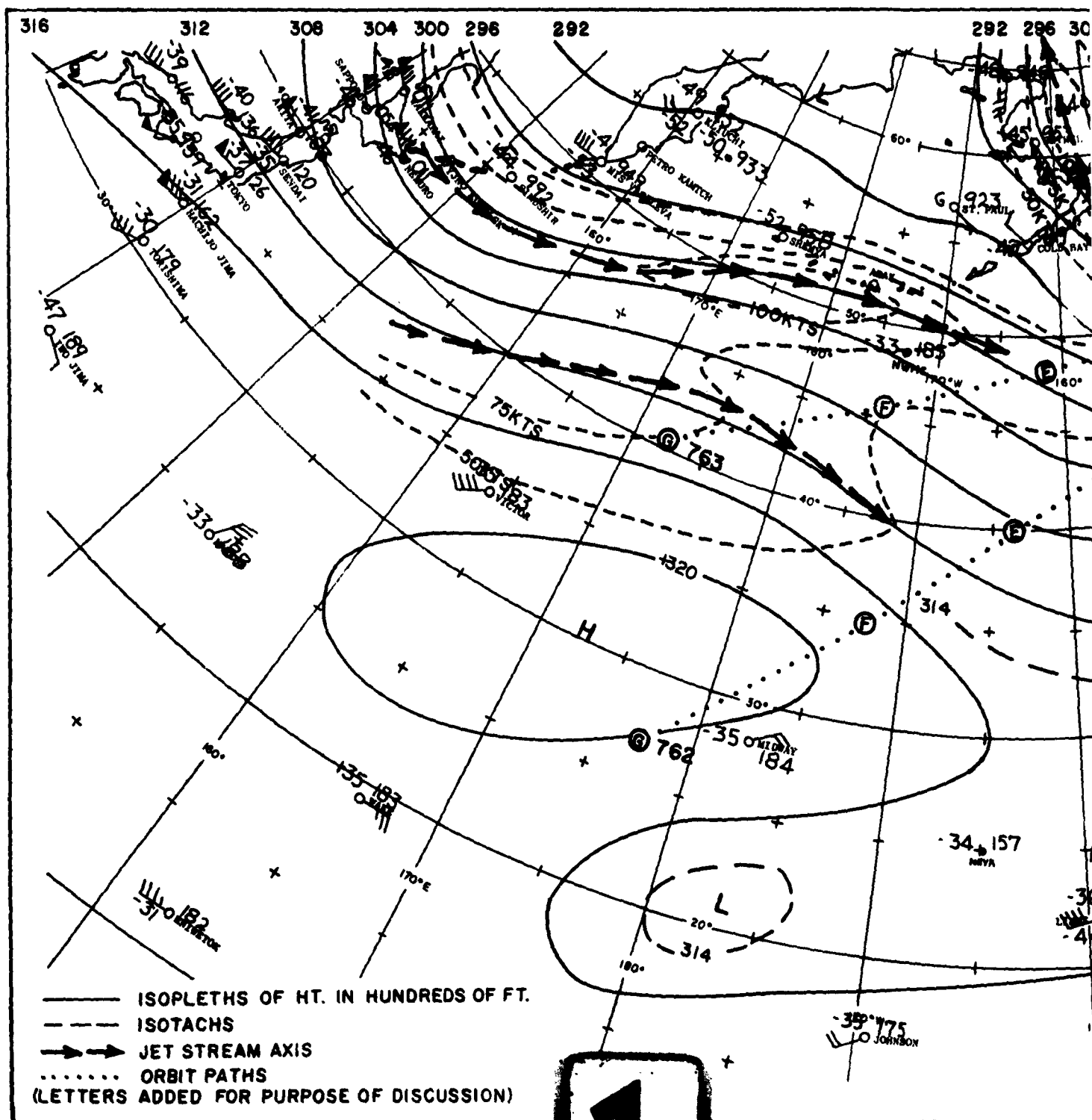


FIG. 27 300-mb MAP, 24 MAY 1961

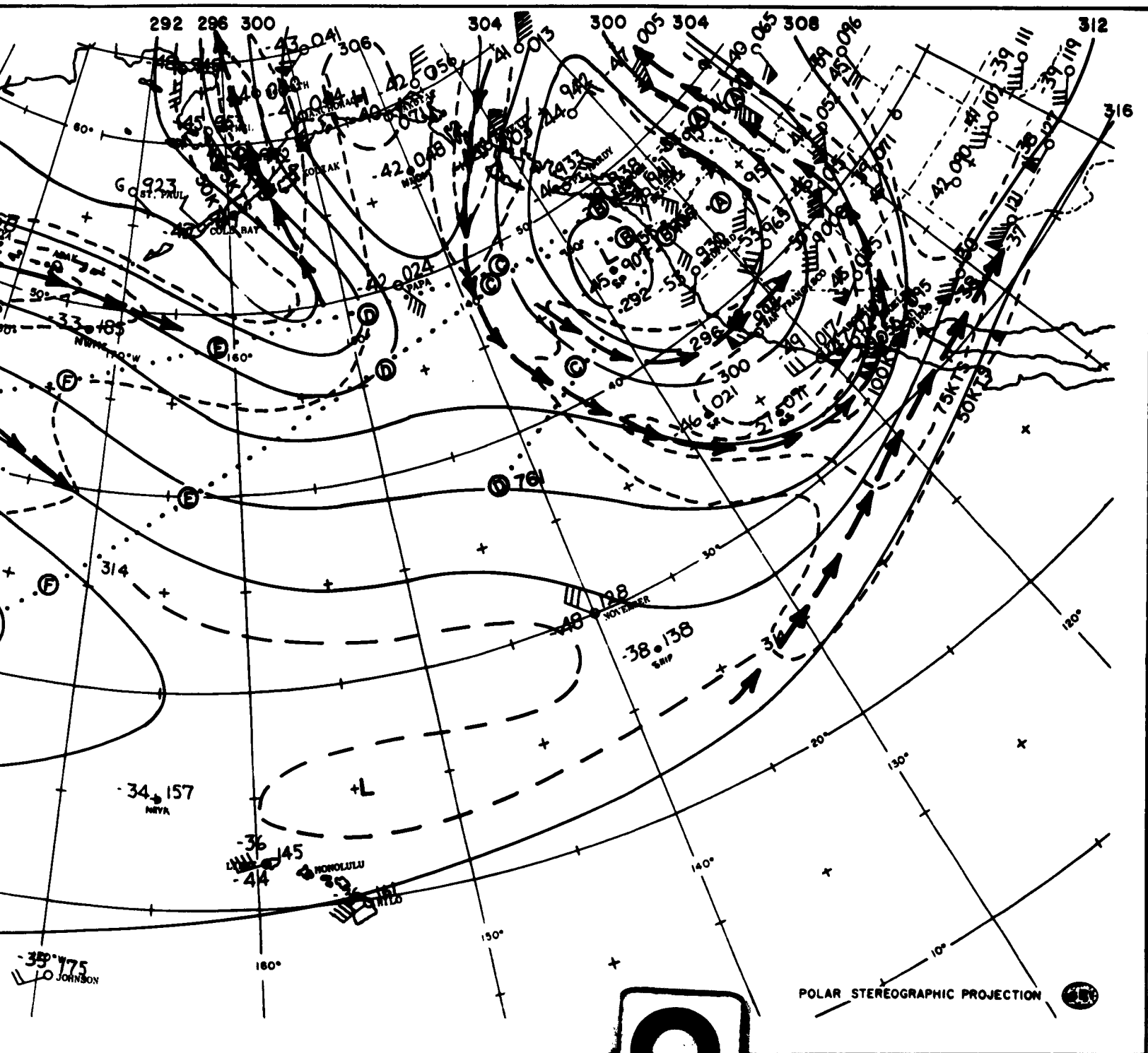


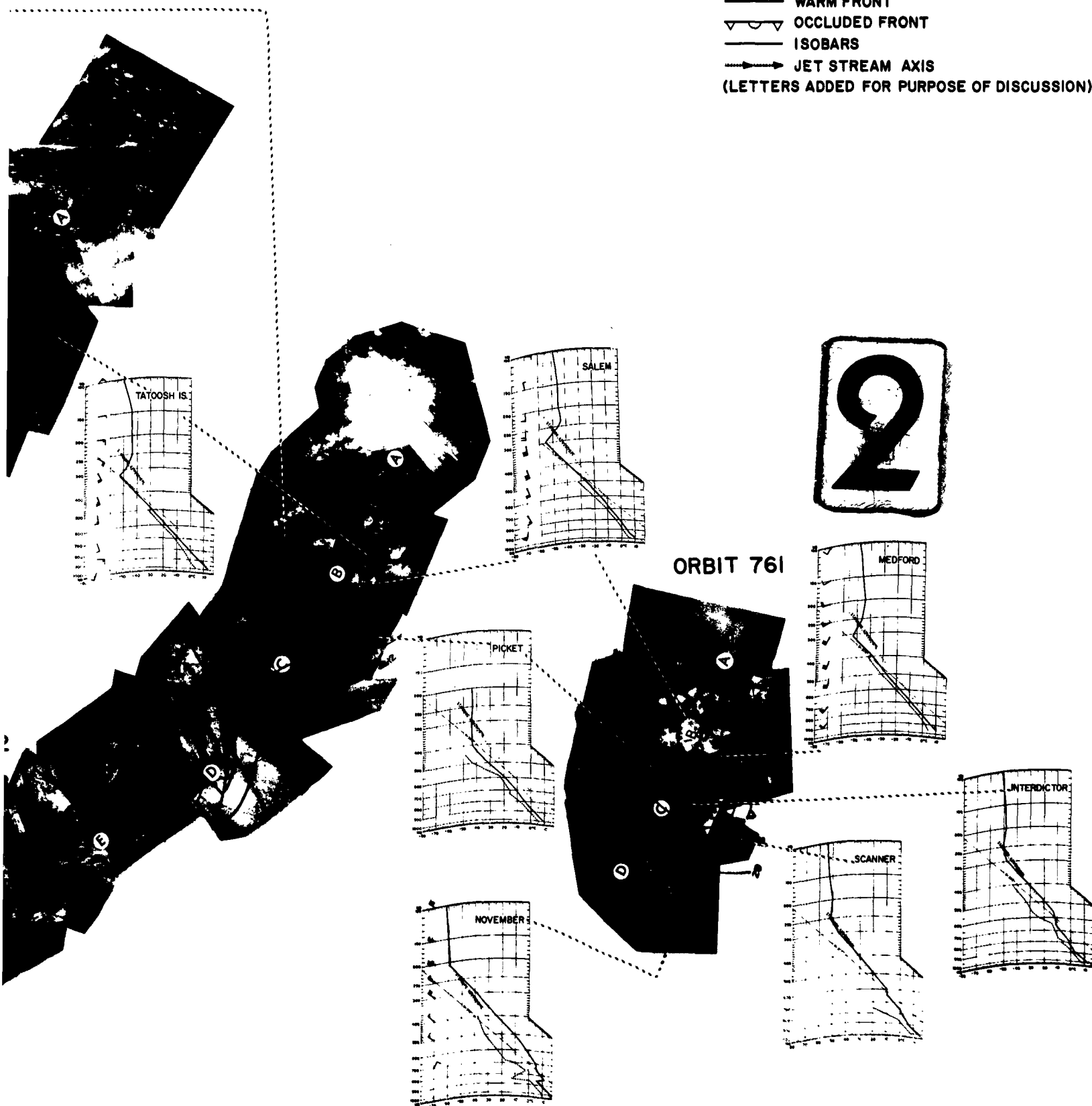
FIG. 27 300-mb MAP, 24 MAY 1960, 0000 G.M.T.

FIG. 27



FIG.28 CLOUD MOSAICS WITH SURFACE PRESSURE SYSTEMS FOR 24 MAY 1964

- ▽▽▽ COLD FRONT
- △△△ WARM FRONT
- ▽△▽ OCCLUDED FRONT
- ISOBARS
- JET STREAM AXIS
- (LETTERS ADDED FOR PURPOSE OF DISCUSSION)

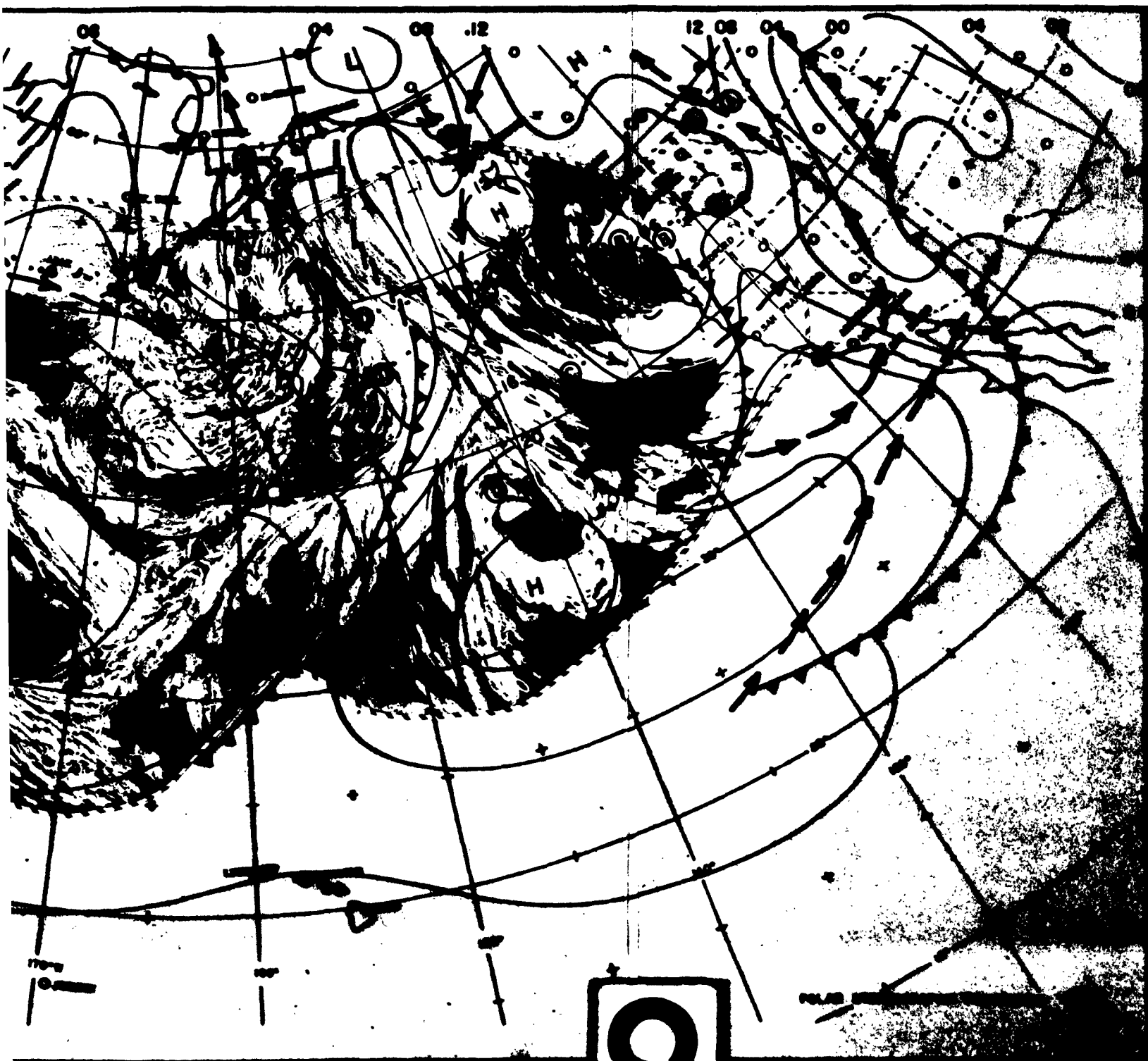


SURE SYSTEMS FOR 24 MAY 1960, 0000 G.M.T.

FIG.28







CATION OF CLOUD PHOTOGRAPHS, 24 MAY 1960, 0000 G.M.T.

FIG. 29

### III TIME SECTIONS OF THE VERTICAL DISTRIBUTION OF SELECTED ATMOSPHERIC PARAMETERS AT A SINGLE STATION, WITH RELATED SATELLITE PHOTOGRAPHS

The first part of this discussion is concerned with the relation of atmospheric structure and motion [as portrayed by time sections of the distributions of temperature, moisture, wind, and computed vertical motion at a single station (OSV Papa, 50°N, 145°W)] to the existence and changes in cloud fields as shown by the station observer and pertinent satellite photographs. The vertical motions were computed according to a procedure outlined by L. A. Vuorela (1957). In the second part of the discussion, this time section will be compared to one constructed for a similar synoptic situation in the north Atlantic prior to the era of meteorological satellites.

#### A. Height-Time Cross Sections at OSV Papa

Figure 30 shows plots for the period 18-24 May 1960 as follows:

- (a) Radiosonde data
- (b) Upper winds and temperatures
- (c) Computed vertical motions
- (d) Temperature-dew point differences.

Figure 31 shows the synoptic satellite photographs.

#### 1. 18 May 1960

At map time 0000 GMT, 18 May, the synoptic analysis (see Figs. 2 and 3) indicate the crest of a rather narrow open-wave cyclone located immediately to the west of the station.

The 300-mb analysis positions a west-east jet stream just north of OSV Papa. The strong winds over OSV Papa are those occurring in the southern perimeter of the maximum isotach area.

The 0000 GMT radiosonde report [Fig. 30(a)] shows the frontal zone to be at the 700-mb level. The maximum wind shear (60 knots in a thousand meters) exists between four and five thousand meters altitude [see Fig. 30(b)] with only light shears (but continued strong winds) above through the 200-mb level.

At this time the surface observer reports a complete overcast of stratocumulus and rain. The photograph of cloud cover on Orbit 676, Frame 5 (Fig. 31) shows a rather amorphous cloud cover in the vicinity of OSV Papa. The photograph (taken at 0105.5 GMT) is, in this case, particularly difficult to interpret. At the station the clouds have the appearance of an amorphous sheet; however, the station is at the edge of the picture where the picture quality is poor. The absence of any outstanding patches of distinct, bright clouds would seem to preclude the presence of towering cumulus in the vicinity of the station, but such might not be visible at this distance and the illumination angle might be adverse.

The temperature-dew point difference for this time (Fig. 31) shows difference values of less than six degrees centigrade below the 550-mb level, indicating that the air in this region is close to saturation.

The distribution of mean vertical velocities [Fig. 30(c)] shows small downward components below the frontal intersection where the air is shown to be stable. Above the front, a zone of upward motion extends almost to the tropopause. The appearance and texture of the clouds shown by the satellite, together with the computed distribution of vertical velocities and temperature-dew point difference, would indicate that the precipitation reported by the observer is probably falling from an upper (altostratus) deck. This zone of precipitation corresponds to the upglide area ahead of the frontal system approaching from the west. Additional evidence that multiple decks exist is implied by the fact that below the frontal intersection the downward component of motion would tend to arrest the vertical development of the stratocumulus clouds reported.

Although actual satellite photographs are not available for the next eighteen hours, some estimation of changes in the cloud systems can be

deduced from the synoptic data. Between 0000 GMT and 1200 GMT the change in the surface wind indicates that the frontal system passes OSV Papa.

At 0600 GMT the moist air extends to the 500-mb level. Upward motion extends to the 250-mb level. Coincident with the passage of the front past the station, the increased downward motion in the frontal area below 850 mb results in the disappearance of the stratocumulus layer, and the report from the observer now indicates only altostratus. This report is confirmation of the multiple cloud deck structure implied in the interpretation of the satellite photographs taken six hours previously.

By 1200 GMT, as the front moves to the east away from the station, the report from the surface observer indicates partly cloudy conditions, with the cloud type unspecified. At this time there is a marked increase in temperature-dew point difference in the moisture tongue above about 800 mb in and adjacent to the front, indicative of marked subsidence or advection of drier air over the station. Upward vertical motion is still shown between about 700 mb and 300 mb but the magnitude is decreasing. The diminished amount of cloud cover reported by the observer seems to correlate more closely, in this case, with the distribution of temperature-dew point differences than it does with vertical motions. Although no cloud types were given by the observer, it may be deduced that this post-frontal clearing is taking place in the altostratus decks since no low clouds were reported in the previous six-hour period.

At 1800 GMT the observer reported an overcast of stratocumulus. The magnitude of temperature-dew point difference shows no material change in the past six hours, but upward vertical motions are being established near the surface. This lower cloud deck is undoubtedly due to the advection of fresh cold air over the warmer ocean with the vertical development of the cloud deck being inhibited by the inversion near the 800-mb level. Upper clouds are extremely unlikely to be present because of the large temperature-dew point differences in the upper levels as well as negative vertical velocities.

The satellite cloud photograph (Fig. 31, Frame 1, Orbit 691) shows that the post-frontal clearing occurring over OSV Papa is quite marked.

Note the contrast between the rather bright, opaque, featureless pattern of the prefrontal clouds east of OSV Papa and the rather patchy, cellular structure over OSV Papa in the post-frontal area.

2. 19 May 1960

The frontal system continues to move eastward and the upper-air analysis shows the jet-stream axis at the 300-mb level to be south of the station (see Figs. 6 and 7). Reference to Figs. 30(a) and 30(b) shows that by 0000 GMT of 19 May 1960 the cold maritime arctic air over OSV Papa extends up to about 480 mb. Warm maritime polar air is present above the frontal intersection. The southerly shift of the jet stream is indicated at this station by the change in the 500-mb temperature, which decreased from  $-19^{\circ}\text{C}$  to  $-25^{\circ}\text{C}$  in the previous 24 hours.

The surface observer reported nine-tenths sky cover composed of cumulus and stratocumulus at 0000 GMT. Reference to the satellite view of the area around OSV Papa shown in Frame 1 on Orbit 691 shows a patchy cloud cover of a cellular structure. The presence of this type of cloud is quite common with the influx of cold air over warmer water. In fact, the radiosonde shows a superadiabatic lapse rate near the surface.

The extent of these clouds in the vertical can be surmised from the distribution of moisture and vertical velocities. At 0000 GMT the temperature-dew point difference of six degrees or less extends to about 700 mb. Positive vertical velocities extend up to the 500-mb level, though the highest values are present below the 850-mb level. These velocity distributions indicate that the stratocumulus deck for the most part does not extend above 5000 or 6000 feet.

Such cellular clouds have been described by Krueger and Fritz (1961) when they studied cases in both the Atlantic and the Pacific. The only vertical sounding available to them in the Pacific was at a station some 730 miles north of the clouds under scrutiny. Here, the sounding was taken close to the cloud element concerned, and the satellite photograph was taken only 90 minutes after the observation. All the atmospheric conditions outlined by Krueger and Fritz that attend such cloud

types, are present--i.e., cold air at the surface being warmed from below, a temperature lapse rate fairly close to adiabatic, and a marked subsidence inversion. The subsidence inversion is close to the 700-mb level (see the sounding for 0000 GMT, 19 May).

The vertical-motion computations show well defined downward components of motion above the 500-mb level, upward motion from the surface to the 700-mb level, and no marked vertical motion between the 700- and 500-mb levels. Clouds probably extend up to 6000 feet. In this case the wind speeds were 10 to 15 knots in the low levels, quite comparable with the wind speeds Krueger and Fritz reported in the Atlantic.

By 0600 GMT the surface observer reports scattered swelling cumulus with rain in sight. Six hours later he reports slight rain showers and a three-fourths coverage of swelling cumulus which by 1800 GMT decreases to scattered towering cumulus (rain in sight) and altocumulus.

Through this period the distribution of temperature-dew point differences shows that high humidities extend from the surface to great heights. Large values of upward motions are found shortly after 1200 GMT extending to the tropopause. Further, there is no strong vertical wind shear below the tropopause. Such values of humidity, vertical motion, and wind shear correlate especially well with reports of towering cumulus and shower activity after 0600 GMT.

Although there are no cloud photographs for 0600 GMT, the satellite photograph taken at 0103 GMT, 20 May 1960, shows the cloud field associated with these towering cumulus and showers to the east and southeast of OSV Papa. Note the hard edges and bright cellular structure of these clouds, typical of towering cumulus. Clustering of these types of clouds (as seen to the southeast of OSV Papa) is indicative of post-frontal conditions where maritime arctic air is involved.

The distribution of winds in the vertical shows that the passage of the upper trough lagged behind the surface front. With the passage of the trough line at all altitudes by 0600 GMT of the 20th, the surface reports again include observations of stratocumulus.

### 3. 20 May 1960

At 0000 GMT, northwesterly flow prevails over OSV Papa as the surface low-pressure area moves to the east of the station. Aloft, the trough line is now well past the station (see Figs. 10 and 11).

The time section shows that the winds over OSV Papa are westerly and northwesterly throughout the sounding, and of moderate speed (20 to 30 knots). There is little speed shear with altitude below the tropopause, which is at the 420-mb level (the lowest height for the tropopause observed throughout the period of this analysis). Moderate wind speeds exist above the tropopause, however. The horizontal wind distribution indicates that the core of the jet stream is southwest of the station. Only a remnant of the strong isotach field (at high altitudes on the cold side of the jet stream) remains over OSV Papa. After 0600 GMT another maximum isotach field approaches the station from the west, moving lower in altitude with time. Concomitant with the approach of these jet-stream winds is the penetration of warm air over the station above the 500-mb level.

At 0000 GMT the surface observer reports five-tenths cloudiness, type unspecified, with rain in sight reaching the surface near to, but not at, the station. From the cloud and precipitation report of the previous six hours, one may surmise that at this time the clouds are probably still of the towering cumulus type. However, at subsequent periods on this day the observer reports scattered to broken stratocumulus clouds. No middle clouds were reported.

The temperature-dew point difference through the period shows a marked and progressive decrease in relative humidity after 0000 GMT as the next frontal system approaches. Values of downward motion also increase during the next 24 hours.

At the time of the satellite picture (0103 GMT) the temperature-dew point differences of six degrees centigrade or less are shown to extend to the tropopause. Vertical motions, though moderate in magnitude, are still positive up to the 500-mb level. The satellite picture shows that the cloud elements to the west of OSV Papa are less bright and

cellular in structure than those over and to the east of this station. The visual appearance of the clouds at OSV Papa is typical of towering cumulus, though in all probability these cumulus tops are not as high as those in the clusters to the south and east of the station since the positive vertical motion does not extend above the 500-mb level, as it did 12 hours earlier.

The clouds to the west of the station are indicative of the type of cloud to pass the station in the next 18 hours. A broader view of these clouds (see Fig. 12, Orbit 705, Point C) shows a marked change in their appearance; they are now arranged more in patches than in individual elements. The observation of high humidities and positive vertical motion to extremely low levels would indicate that these clouds are probably low stratiform in character. Perusal of the photograph over OSV Papa (Orbit 720, Frame 7) taken at 0155 GMT of the 21st of May shows that the cloud field to the east of the station has a stratified appearance, and one can presume that such cloud cover would have been over OSV Papa at 1800 GMT of the 20th.

#### 4. 21 May 1960

The northwesterly flow present at all altitudes over the station on 20 May 1960 persists as the ridge of high pressure intensifies in the eastern Pacific and continues to move slowly toward the station. The 300-mb analysis shows the jet-stream location to be just to the east of OSV Papa (see Figs. 14 and 15).

On this day the radiosonde at OSV Papa shows marked warming above the frontal inversion at the 500-mb level. This warming penetrates to lower altitudes with time, as the surface front approaches. A temperature inversion is also present below the 850-mb level.

The surface observer report for 0000 GMT indicates nine-tenths sky cover of stratocumulus, with openings. Subsequent reports show this sky cover remaining essentially unchanged for the next 18 hours. The closest satellite photograph is from Orbit 720, Frame 7, taken at 0155 GMT. The photograph shows a rather amorphous cloud sheet, opaque and



featureless, extending over a considerable area around the station, in agreement with the above-mentioned surface-observer reports of sky cover.

South of OSV Papa a ship observer at 48°N, 143°W reported seven- to eight-tenths sky cover of stratocumulus and cirrus ( $Ch_1$ , filaments of cirrus scattered, and not increasing). These cirrus are probably present over OSV Papa at the satellite picture time as well as at 0000 GMT. This inference is based on the knowledge that at 0000 GMT the radiosonde data at OSV Papa and the jet-stream location with respect to the station are favorable for the existence of cirrus. The fact that cirrus is not reported by the observer could be explained by either the inadequate field of view afforded the observer by the small breaks in the low cloud cover or by the fact that the cirrus clouds are not yet close enough to the station to be seen by the observer. An inspection of the southern portion of the photograph where cirrus are present shows that the cloud character has a decided striated and broken appearance, with the rows oriented parallel to the wind flow. These striations extend northwestward to the edge of the photographs, passing immediately to the west of OSV Papa.

Throughout the 24-hour period the temperature-dew point difference shows that high humidities are found only in the levels below 900 mb. Marked dryness exists above this level, with the lowest humidities occurring in and along the frontal surface. Further, the time section shows downward vertical motion from about 300 mb to 750 mb, being strongest between the 300- and 400-mb levels and decreasing in magnitude in the lower levels.

During the entire period the winds remain strong at high altitudes, with little directional change. These sustained, high wind speeds indicate that little eastward translation in the jet stream is taking place, but that a fairly uniform maximum isotach field oriented northwest-southeast is quasi-stationary over OSV Papa.

The striations mentioned above are considered as evidence of diminished low cloud cover due to evaporation caused by strong subsidence along the front below the jet stream, with cirrus clouds aloft. The extent and orientation of the diminished cloud cover just west of OSV Papa

portrayed in the satellite photograph is visual evidence of the extent of the subsidence that exists beneath this jet stream.

5. 22 May 1960

The surface map shows the ridge line of the anti-cyclone to be almost directly over the station. The 300-mb analysis, however, indicates that at high altitudes the ridge line is still to the west of OSV Papa (see Figs. 18 and 19).

Reference to the time section of winds and temperatures shows that the frontal system has moved past the station; the high jet-stream winds aloft begin to decrease after 0000 GMT, and the tropopause reaches the 170-mb level. Marked changes occur in the distribution of isopleths of temperature-dew point differences during the period. The pronounced low humidities evident over the station during the previous 24 hours are still present at 0000 GMT on the 22nd. At this time (0000 GMT), positive vertical velocities exist between the 600-mb and 400-mb levels. These motions actually developed shortly after 0600 GMT on the previous day (21 May). They are capped by downward motion between the 400-mb and 250-mb levels, with upward motion again occurring above the latter level. By 0600 GMT of this day, a tongue of moist air appears through almost the entire column to the 300-mb level. It remains substantially unvarying for the next 12 hours.

The satellite photograph, Fig. 31, Orbit 733, Frame 20, shows the cloud cover in the vicinity of OSV Papa at 2318 GMT, 21 May, some 42 minutes prior to the observer's report. The gridded photograph shows a rift in the cloud cover in close proximity to the station. In all probability this rift is the same one that was evident west of OSV Papa on Orbit 720, Frame 7, at 0155 GMT of the previous day.

At 0000 GMT the surface observer reported cirrus  $C_{H_4}$  (cirrus, often hook-shaped, gradually spreading over the sky and usually thickening as a whole) which to some degree supports the suggestion of probable existence of cirrus over the station the day before. The light cloud streak extending south of the station in this photograph is probably an extension of the cirrus. At 0600 GMT the sky is reported as obscured

with fog; at 1200 GMT the observer reported an overcast of stratus; and at 1800 GMT an obscured sky with rain distant from the station was reported.

The cloud field to the west of OSV Papa is characterized by a particularly bright streak some two degrees to the west, followed by an extensive sheet of amorphous cloud of a somewhat granular appearance. A substantial proportion of this cloud mass is undoubtedly the low stratus that the observer reported through the 22nd. The appearance of the bright streaks in the vicinity of OSV Papa must be interpreted as an overlying deck of high clouds. Indeed, at 0000 GMT of the 23rd (see Orbit 748, Frame 14) the observer reports both altocumulus and stratus.

6. 23 May 1960

The 0000 GMT surface synoptic map shows the ridge line quite close to OSV Papa. It actually passes the station between 0600 and 1200 GMT. At the 300-mb level a blocking high was developed in the eastern-central Pacific. The jet-stream location is now decidedly to the east of OSV Papa (see Figs. 22 and 23).

Reference to the time section of the vertical distribution of winds shows that the ridge line passes the station at all levels between the 0000 and 1200 GMT observation. The temperature lapse rate reveals the presence of a stable layer between 650 and 550 mb. Small magnitudes of positive vertical motion are apparent from the surface to the 500-mb level, and again from approximately the 350-mb level up to the tropopause. The isopleths of temperature-dew point difference show high humidities confined below the 800-mb level, with a pronounced layer of low humidity, centered at the 500-mb level, present just above the inversion layer. Such dryness, of course, would be expected near the center of the ridge.

The distribution of clouds in and around the vicinity of OSV Papa at 0008 GMT, 23 May 1960, is shown in Frame 14 of Orbit 748 (Fig. 31). The most distinctive features of this cloud cover are the very extensive clear area to the east of OSV Papa, and the streaky nature of the cloud cover to the west of the station.

At 0000 GMT, the observer reports seven- to eight-tenths cloud cover composed of stratus or fractostratus, and altocumulus ( $M_3$ --thin altocumulus not changing much, and at a single level). At 0600 GMT, the observer reports stratocumulus. After the passage of the ridge, the stratocumulus overcast continues, accompanied by light fog. At 1800 GMT, the sky cover is reported as nine-tenths, or overcast with openings, but the cloud type is not indicated.

In view of the surface observer report of altocumulus made eight minutes before the time of the satellite photograph, plus the fact that another ship report near 42°N, 140°W also shows altocumulus, it is logical to conclude that the brighter portions of the aforementioned streakiness in the clouds at and to the west of OSV Papa are long filaments of altocumulus oriented parallel to the wind flow.

Undoubtedly the partial clearing or streakiness in the clouds is a reflection of the low humidities in the middle tropospheric layer that results from the marked subsidence accompanying the passage of the ridge line over the station. Pronounced downward motion is noticed over OSV Papa in the middle layers from the 22nd of May (when the station was just east of the ridge line) to 1800 GMT of the 23rd when the ridge line passes; after this time the overrunning moisture of the next frontal system to the west begins to make its appearance over the station. A satellite photograph taken some eight hours later (Frame 14, Orbit 763, 0058 GMT, May 24) affords a view of the partial clearing accompanying the passage of the ridge line. In this picture the thin altocumulus is now over and to the east of OSV Papa. The bright opaque cloudiness just to the west shows the prefrontal cloud shield associated with the on-coming frontal system.

#### 7. 24 May 1960

The surface map, 0000 GMT, shows a cyclone just to the west of OSV Papa. At the 300-mb level the blocking high-pressure cell is located well to the north of the station, with westerly flow already re-established in the middle latitudes (see Figs. 26 and 27).

The time section of the distribution of winds aloft shows a change from southerlies to easterlies after 0000 GMT, indicating that the center of a low-pressure cell is passing south of the station.

The time section of the distribution of vertical velocities shows that at the beginning of the period, pronounced downward motion prevails above the 500-mb level, with maximum magnitudes near the 400-mb level. These high values of downward motion coincide with the upper and steeply sloped portion of the well-defined subsidence layer. Later in the period these negative vertical velocities are replaced by moderate values of positive vertical motion which then extend, uninterrupted, up to the 300-mb level.

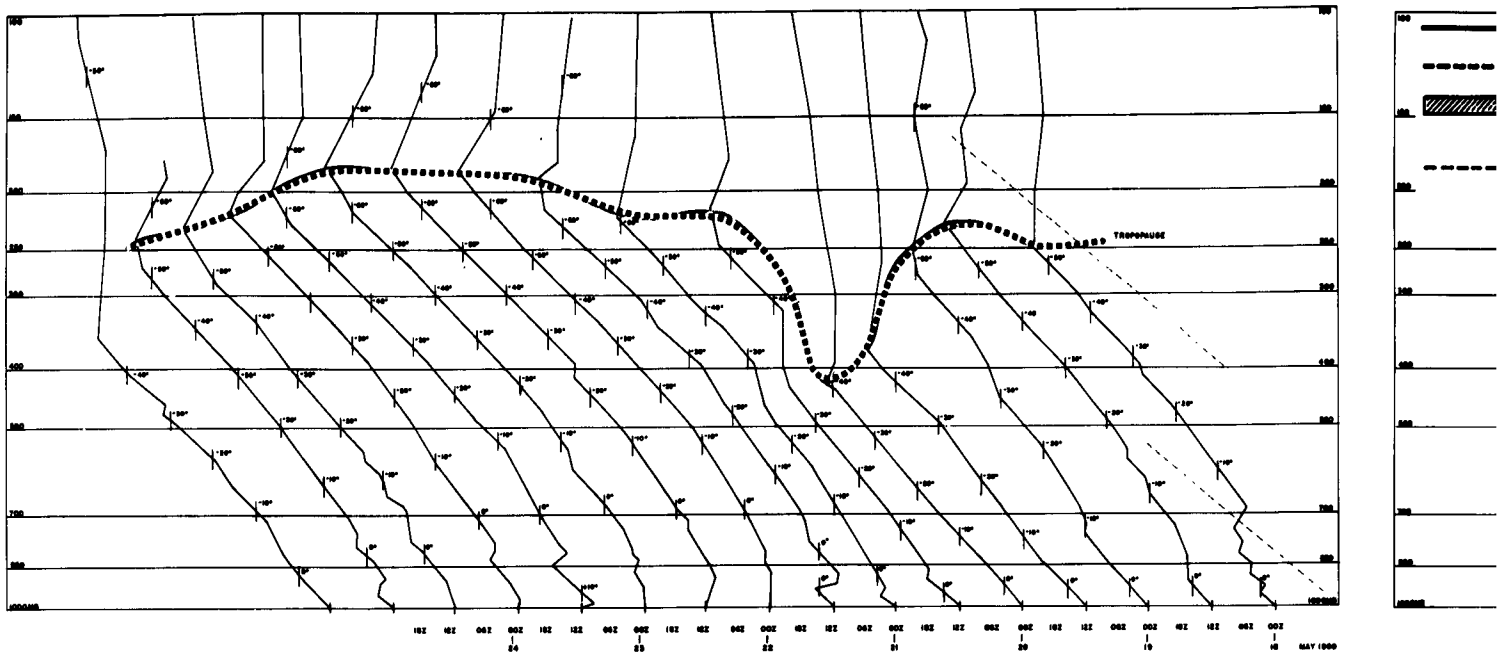
In addition, as the front approaches from the west, the vertical distribution of temperature-dew point difference shows a pronounced increase in humidity aloft.

At 0000 GMT the observer at OSV Papa reports the sky to be completely overcast with stratocumulus and thin altocumulus ( $C_{M-3}$ --cloud elements not changing much, and at a single level). Thin altocumulus of this type was reported some 24 hours previously at the station, and a comparison of the appearance of the clouds over OSV Papa in the photographs of Orbit 748, Frame 14, with those of Orbit 763, Frame 14 show a great similarity in appearance--i.e., a thin, streaky, and fibrous character. In both photographs the streaks are parallel to the wind, though in the latter case the winds were from the south-southeast and in the former case they were from the north-northwest. This thin altocumulus probably is present throughout the whole time period of the 24th, its presence not being reported due to the low overcast cloud cover.

Frame 14 of Orbit 763 shows the cloud distribution at 0058 GMT on 24 May. The prefrontal cloud shield of the advancing frontal system is seen to the west of OSV Papa. The partial clearing in the retreating ridge is seen in the northeast sector of the picture. Configuration of the presence of altocumulus is seen in the granular, filmy appearance of the clouds. The streaks are oriented from the southeast to the northwest about parallel to the observed wind field (south-southeast winds).

Later in the period these winds at OSV Papa become easterly, but their orientation with respect to cloud cover cannot be ascertained due to the lack of satellite photographs.

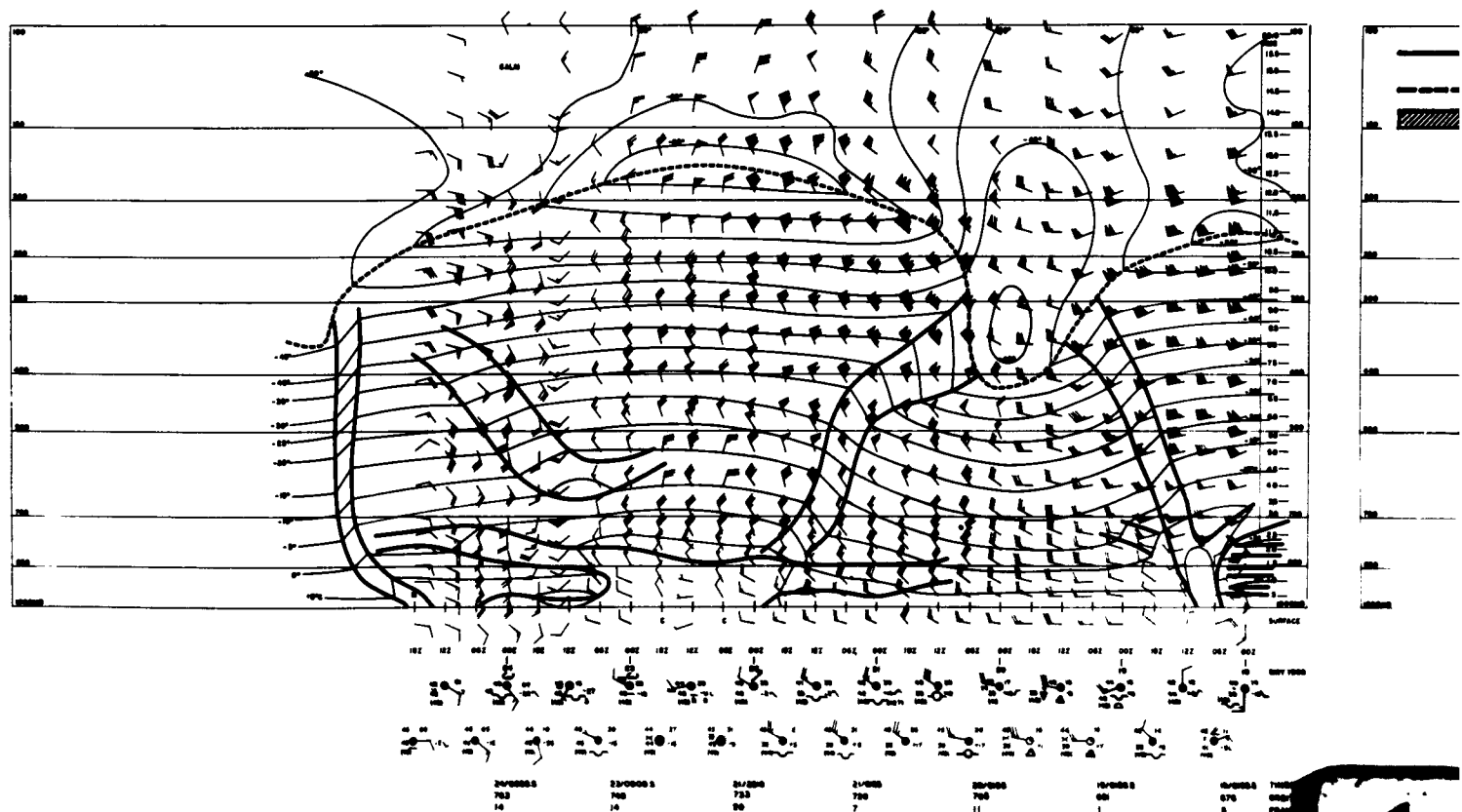
With the approach of a cold front to the station on the 25th of May, the prefrontal patterns of vertical velocity and temperature-dew point depression are rather similar to the pre-cold-frontal patterns over the station on the 18th of May. Notice especially that a deep layer of positive vertical velocities is embedded in the warm air ahead of the front. A tongue of moist air is also evident in advance of both fronts, together with a pronounced zone of drying extending down to about the 800-mb level within the frontal boundary itself. In both instances the lower levels remain moist.



(a) Temperature Lapse Rates. Small Tick Marks Indicate Temperature ( $^{\circ}\text{C}$ ) in Ten Degree Increments.

(c) Iso-

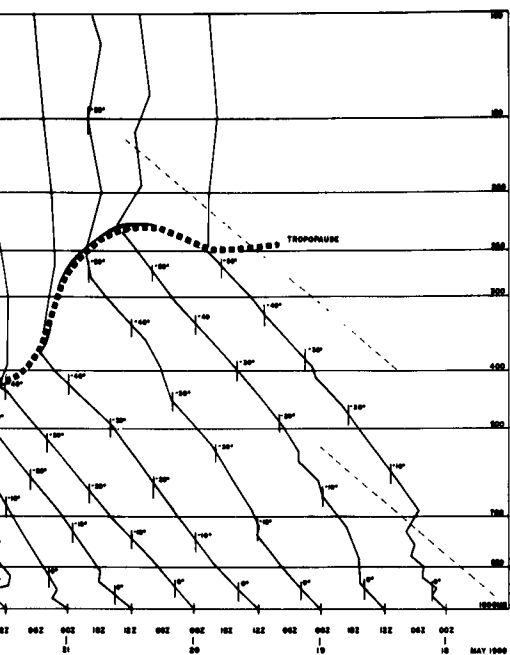
repi



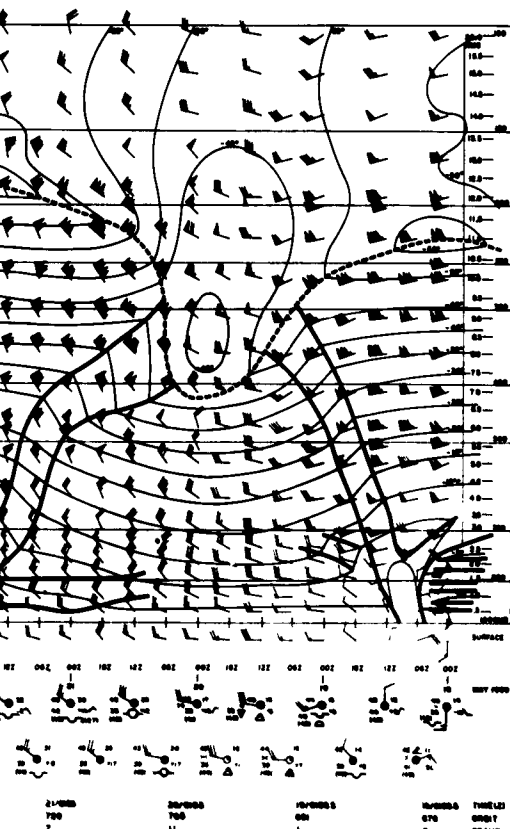
(b) Isopleths of Temperature and Winds

FIG. 30 TIME SECTION OF THE VERTICAL DISTRIBUTION OF (50°N; 145°W), MAY 18-24, 1960. SURFACE REPORTS INTERSECTION, HEAVY SOLID LINE INDICATES FROM

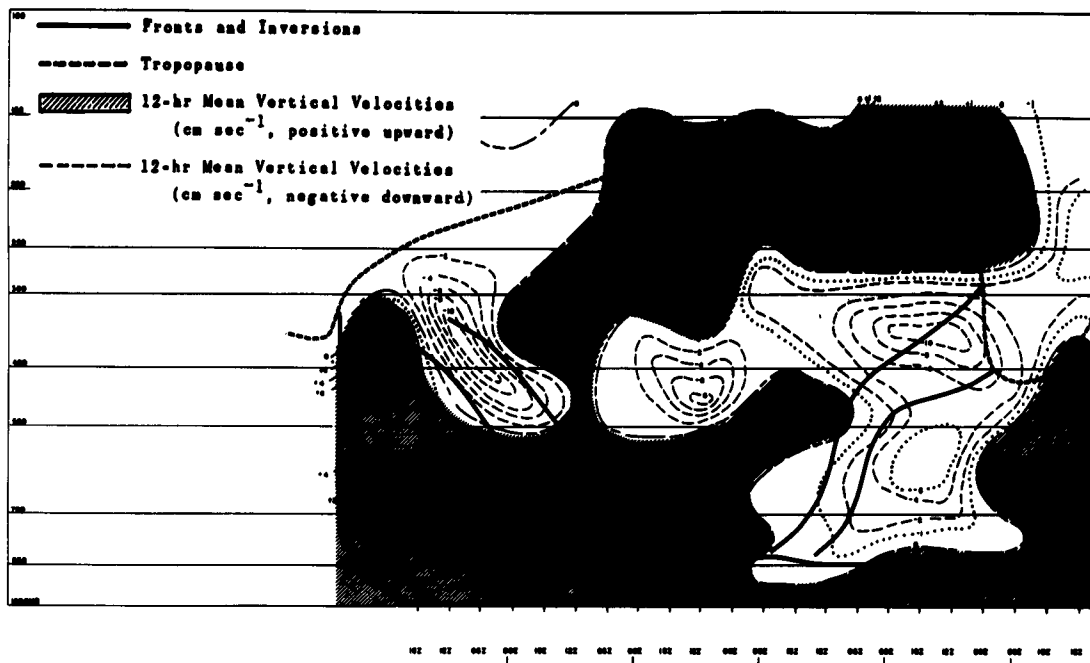




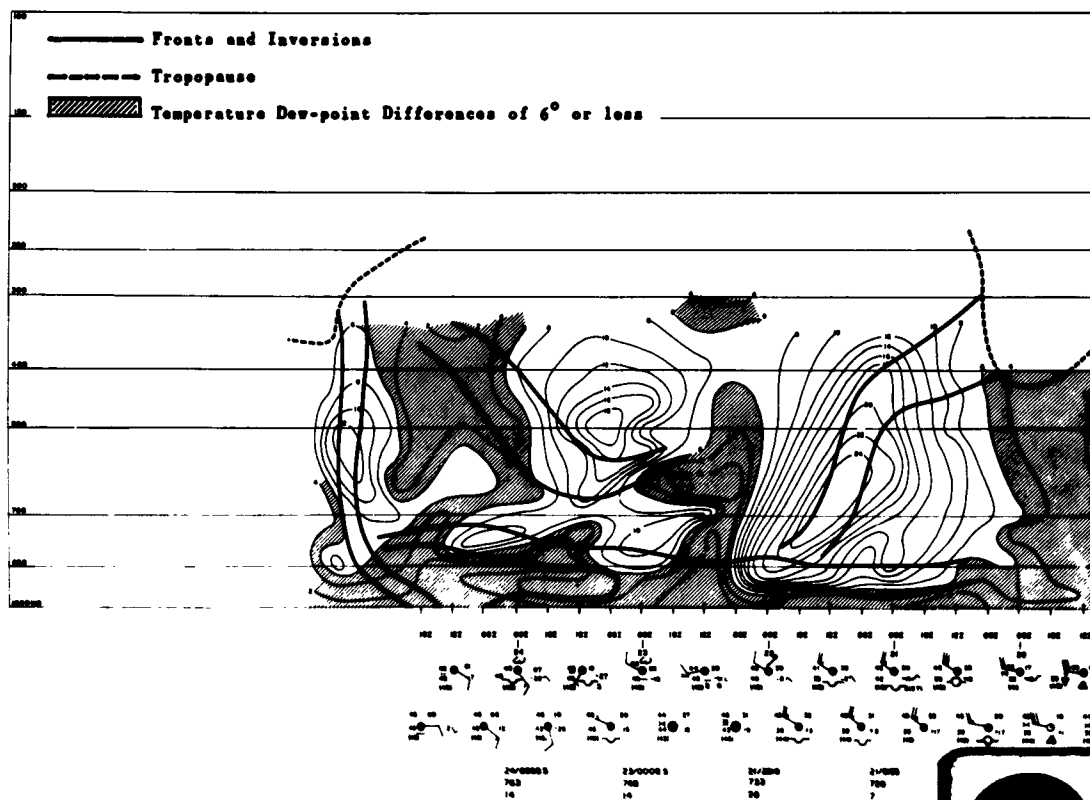
Temperature ( $^{\circ}\text{C}$ )



SECTION OF THE VERTICAL DISTRIBUTION OF SELECTED ATMOSPHERIC PARAMETERS AT OSV PAPA (45 $^{\circ}$ W), MAY 18-24, 1960. SURFACE REPORTS ADDED. HEAVY DASHED LINE SHOWS TROPOPAUSE SECTION, HEAVY SOLID LINE INDICATES FRONTS AND INVERSIONS



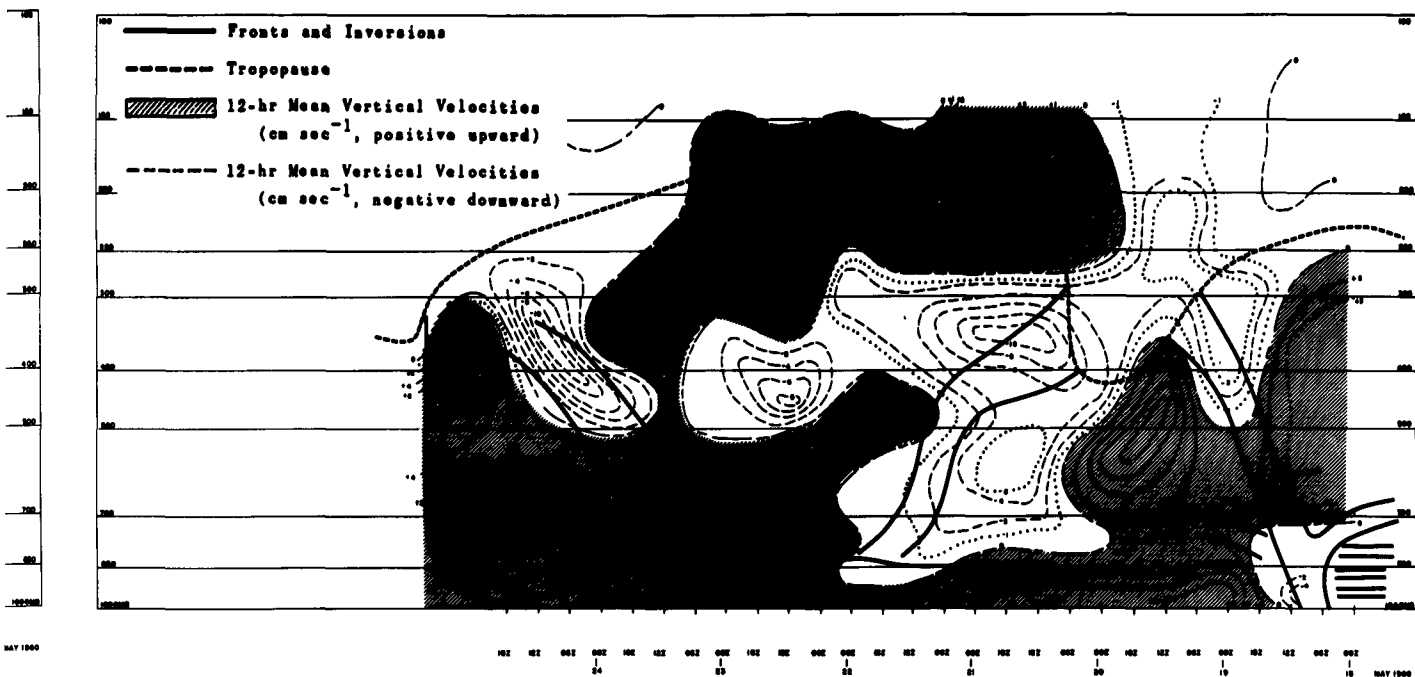
(c) Isopleths of Vertical Velocity (in  $\text{cm sec}^{-1}$ ). Positive (upwards) Vertical Velocity represented by solid lines (shaded); Negative (downwards) Vertical Velocity represented by dashed lines.



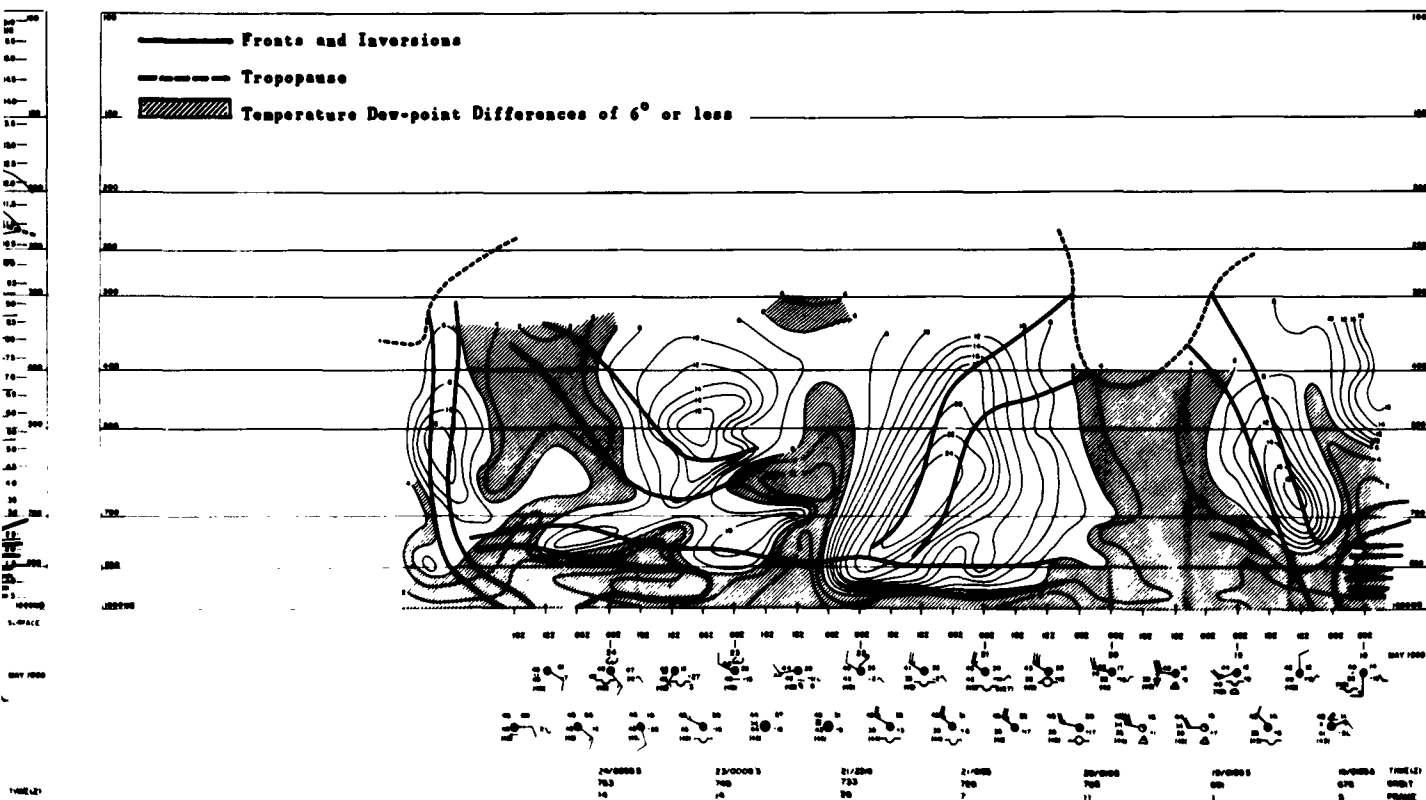
(d) Isopleths of Temperature Dew-point Difference ( $^{\circ}\text{C}$ ). Differences of  $6^{\circ}$  or less are shown.







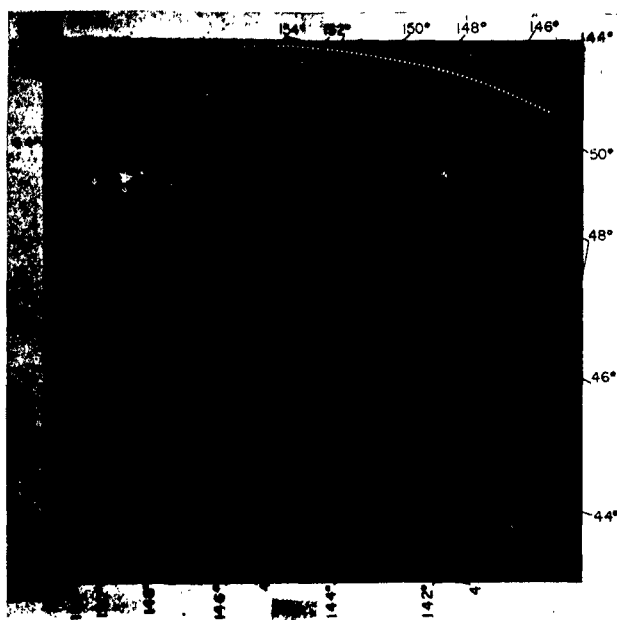
(c) Isopleths of Vertical Velocity (in  $\text{cm sec}^{-1}$ ). Positive (upwards) Vertical Velocities represented by solid lines (shaded); Negative (downwards) Vertical Velocities by dashed lines.



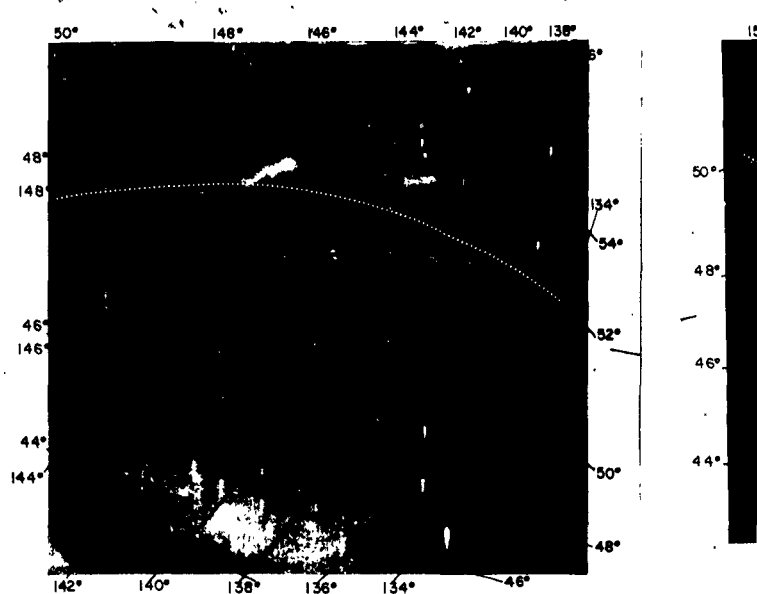
(d) Isopleths of Temperature Dew-point Difference ( $^{\circ}\text{C}$ ). Differences of  $6^{\circ}\text{C}$  or less are shaded.

OF SELECTED ATMOSPHERIC PARAMETERS AT OSV PAPA  
 TS ADDED. HEAVY DASHED LINE SHOWS TROPOPAUSE  
 FRONTS AND INVERSIONS

FIG. 30



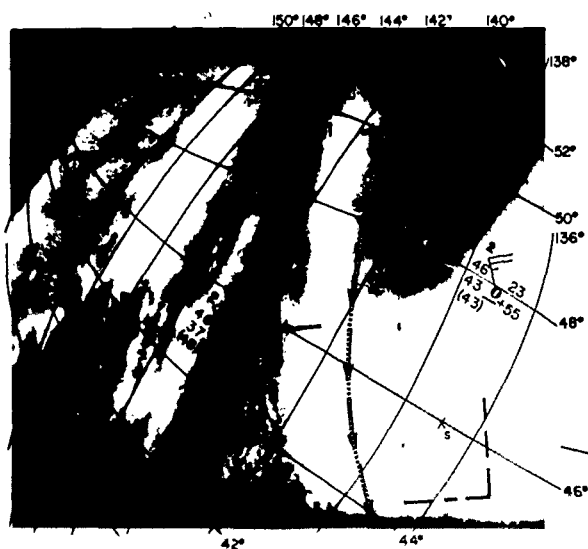
ORBIT 676 FRAME 5 0105.5 GMT 18 MAY 1960  
SURFACE DATA 0000 GMT 18 MAY 1960



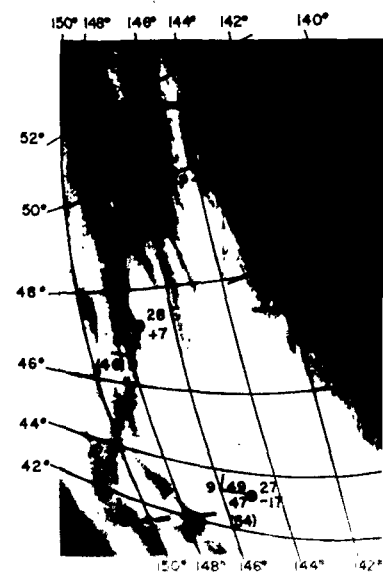
ORBIT 691 FRAME 1 0156.5 GMT 19 MAY 1960  
SURFACE DATA 0000 GMT 19 MAY 1960

ORBIT

-----> JET STREAM



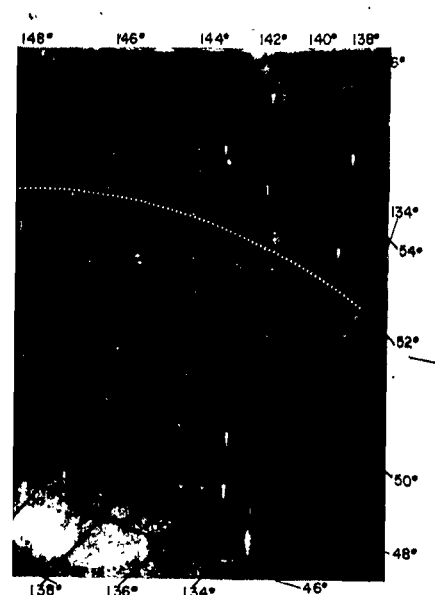
ORBIT 733 FRAME 20 2318.0 GMT 21 MAY 1960  
SURFACE DATA 0000 GMT 22 MAY 1960



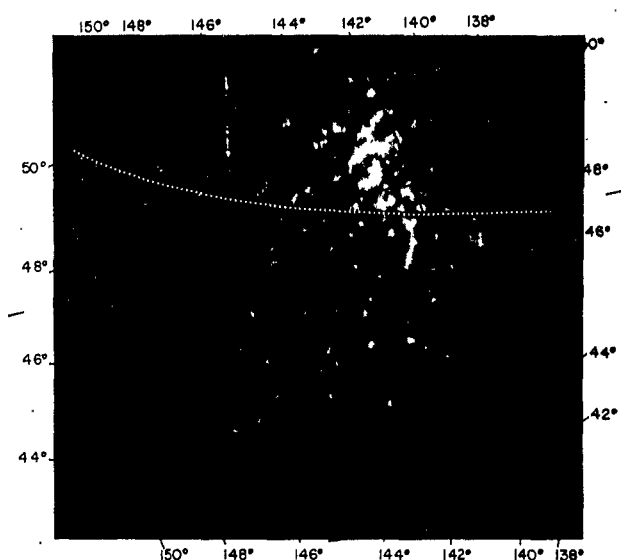
ORBIT 748 FRAME 14 0008.  
SURFACE DATA 0000 GMT

1

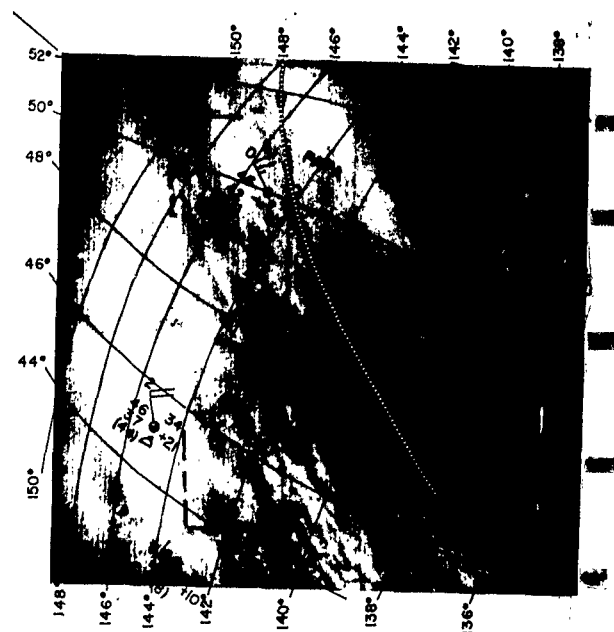
FIG. 31 SATELLITE PHOTOGRAPHS (Camera 2) FOR OSV PAPA (50°N 1



AME 1 0156.5 GMT 19 MAY 1960  
DATA 0000 GMT 19 MAY 1960

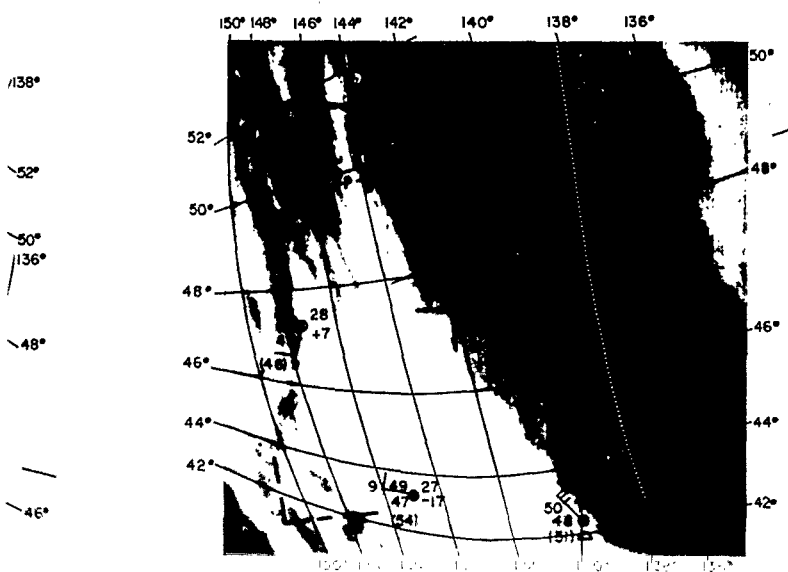


ORBIT 705 FRAME 11 0103.0 GMT 20 MAY 1960  
SURFACE DATA 0000 GMT 20 MAY 1960

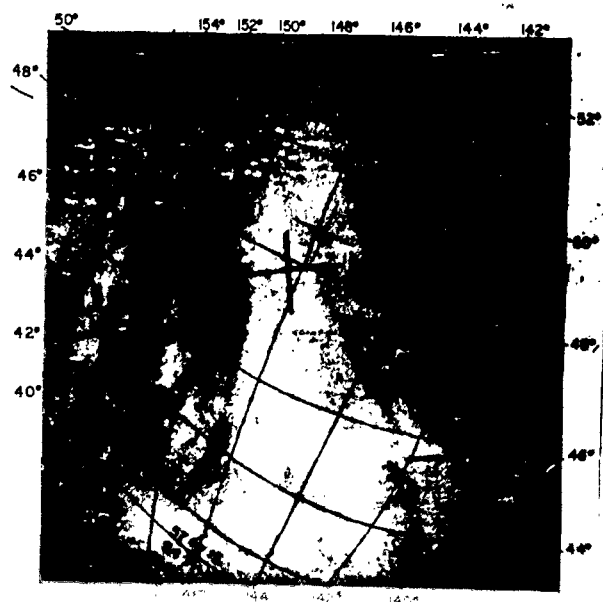


ORBIT 720 FRAME 7 0155.0 GMT 21 MAY 1960  
SURFACE DATA 0000 GMT 21 MAY 1960

→ JET STREAM AXIS



1960 ORBIT 748 FRAME 14 0008.5 GMT 23 MAY 1960  
SURFACE DATA 0000 GMT 23 MAY 1960



ORBIT 763 FRAME 14 0058.5 GMT 24 MAY 1960  
SURFACE DATA 0000 GMT 24 MAY 1960

2

Camera 2) FOR OSV PAPA (50°N 145°W) AND VICINITY CORRESPONDING WITH DATA OF FIG. 30

FIG. 31

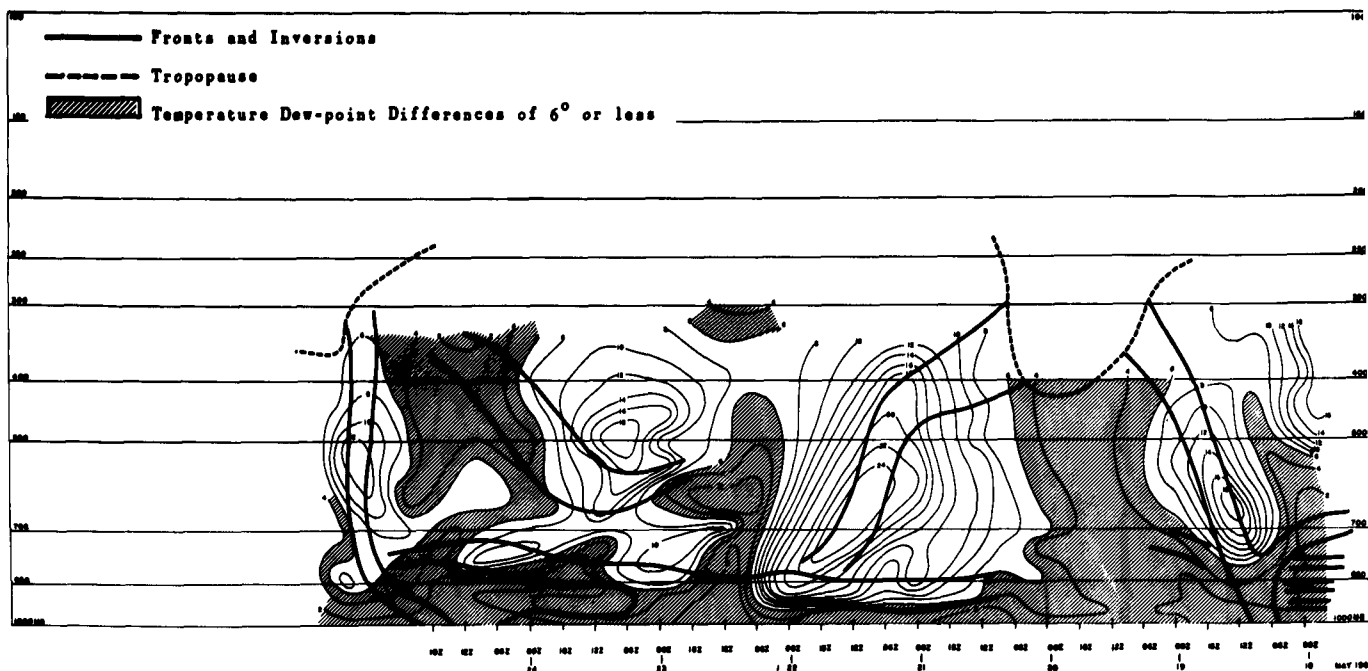
B. Comparison with Cross Section for a Similar Synoptic Situation in the Atlantic

Having obtained the distribution of atmospheric motion through this blocking situation, the next step was to ascertain (1) if the atmospheric motions were similar to those in other blocking situations--qualitatively if not quantitatively--and (2) if the cloud systems and changes in cloud systems are comparable in similar situations. Should the satellite data show the cloud systems to be similar, then indeed there would be a basis for postulating a cloud-cover model useful for operational forecasting purposes during such synoptic situations.

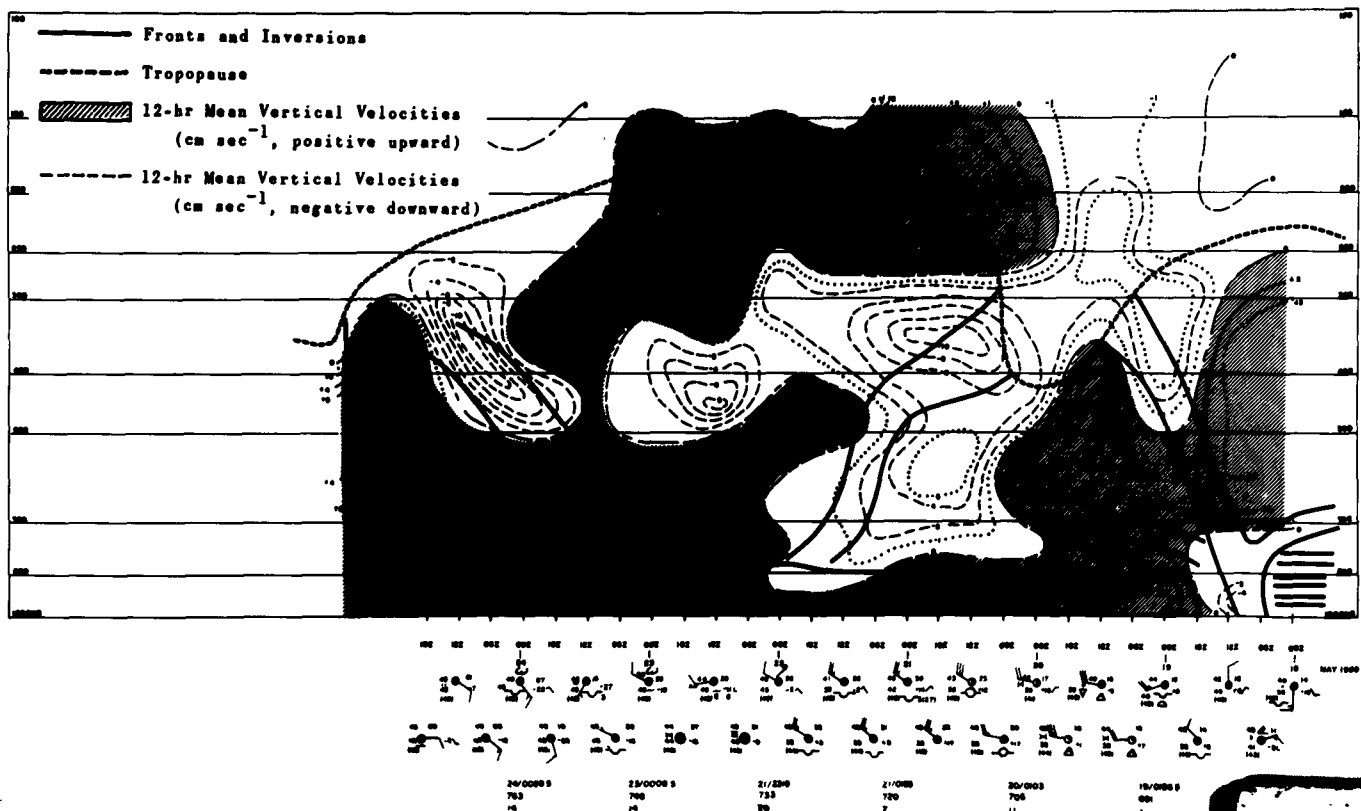
Vuorela (1957) has presented a detailed discussion of a synoptic situation (15-17 January 1951) similar to that described in this report. Vuorela's study describes the establishment and maintenance of a well developed blocking anti-cyclone associated with an invasion of tropical air aloft into higher latitudes, in the north Atlantic. The air masses involved were of the same type as those involved in this study.

He presents an analysis of time cross sections of the distributions of winds and temperatures, isopleths of temperature-dew point differences, and vertical velocities at a single station (Lerwick, Shetland Islands). This station bears a similar but not exact spatial relationship to the sequence of events during the evaluation and existence of the synoptic situation, as does OSV Papa in this report, although the time sections at OSV Papa characterize a somewhat more southerly part of the trough-ridge complex than that over Lerwick. Further, the blocking system in the Pacific seems to be somewhat slower moving than its counterpart in the Atlantic. Comparable segments of the pressure pattern traverse Lerwick in 51 hours while at OSV Papa the similar sequence of events extends over 144 hours. The amplitudes of the blocking ridges in both cases are approximately the same, the wave length of the blocking system in the Pacific being only slightly greater.

Figure 32 is included to facilitate a cross comparison of the conditions and resulting computations in both cases.



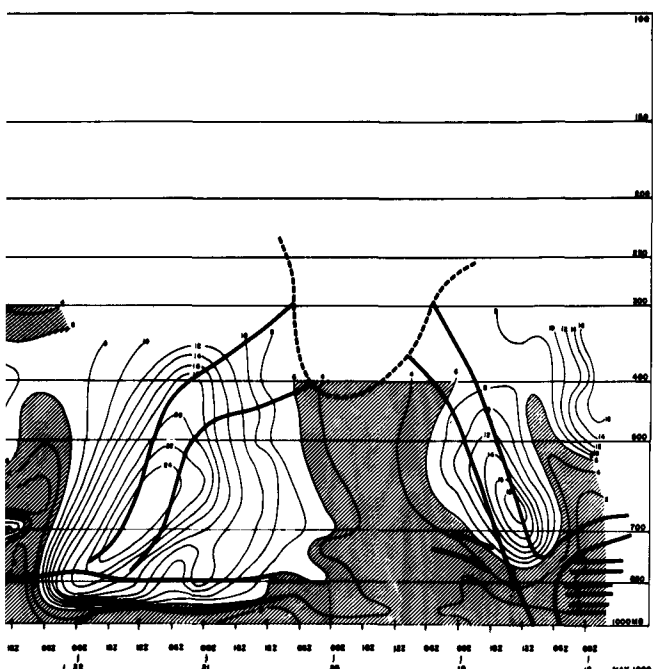
(a) Isopleths of Temperature Dew-point Difference for OSV "Papa".



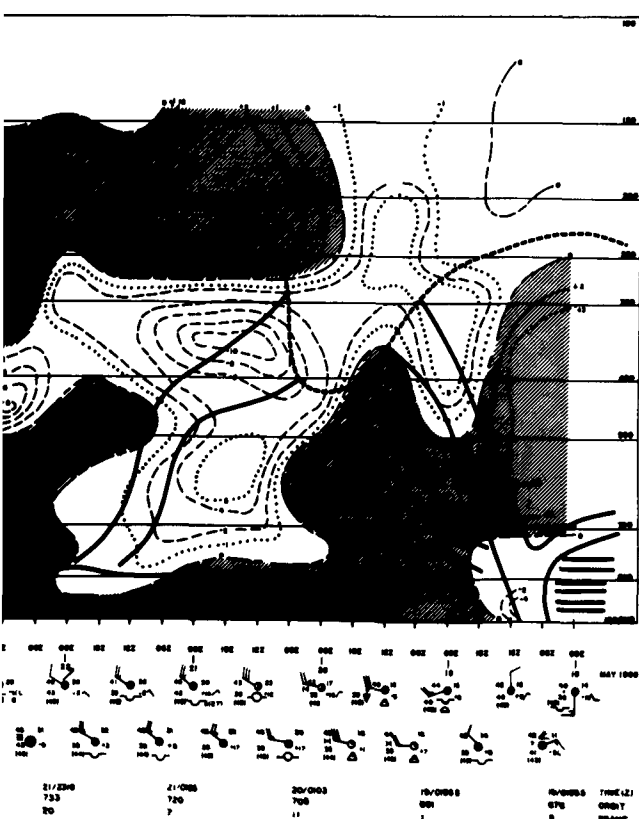
(b) Isopleths of Vertical Velocity (in  $\text{cm sec}^{-1}$ ) for OSV "Papa". Surface Report

FIG. 32 COMPARISON OF TIME SECTION  
AT LERWICK (Shetland Islands)

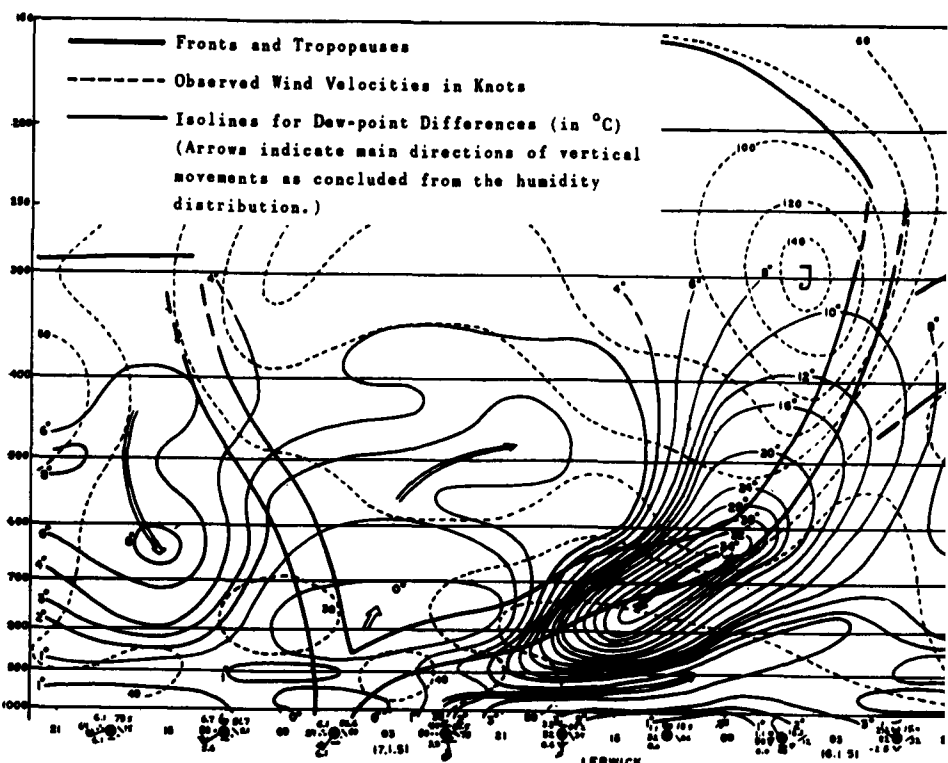




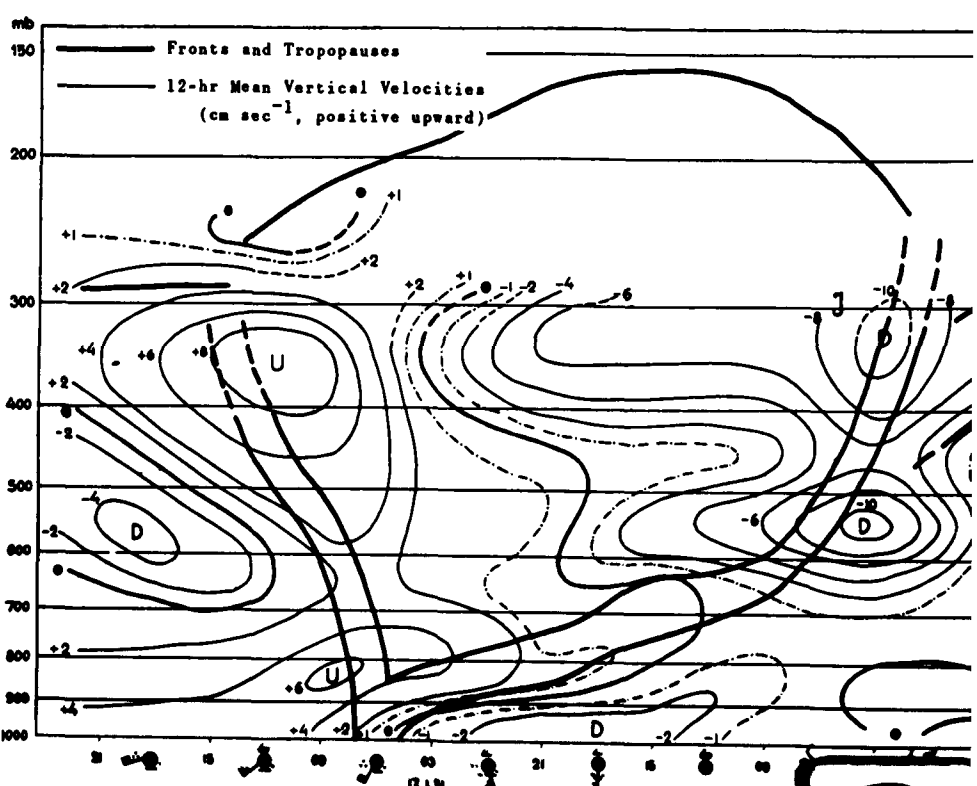
reference for OSV "Papa".



$\text{cm sec}^{-1}$ ) for OSV "Papa". Surface Reports Added.

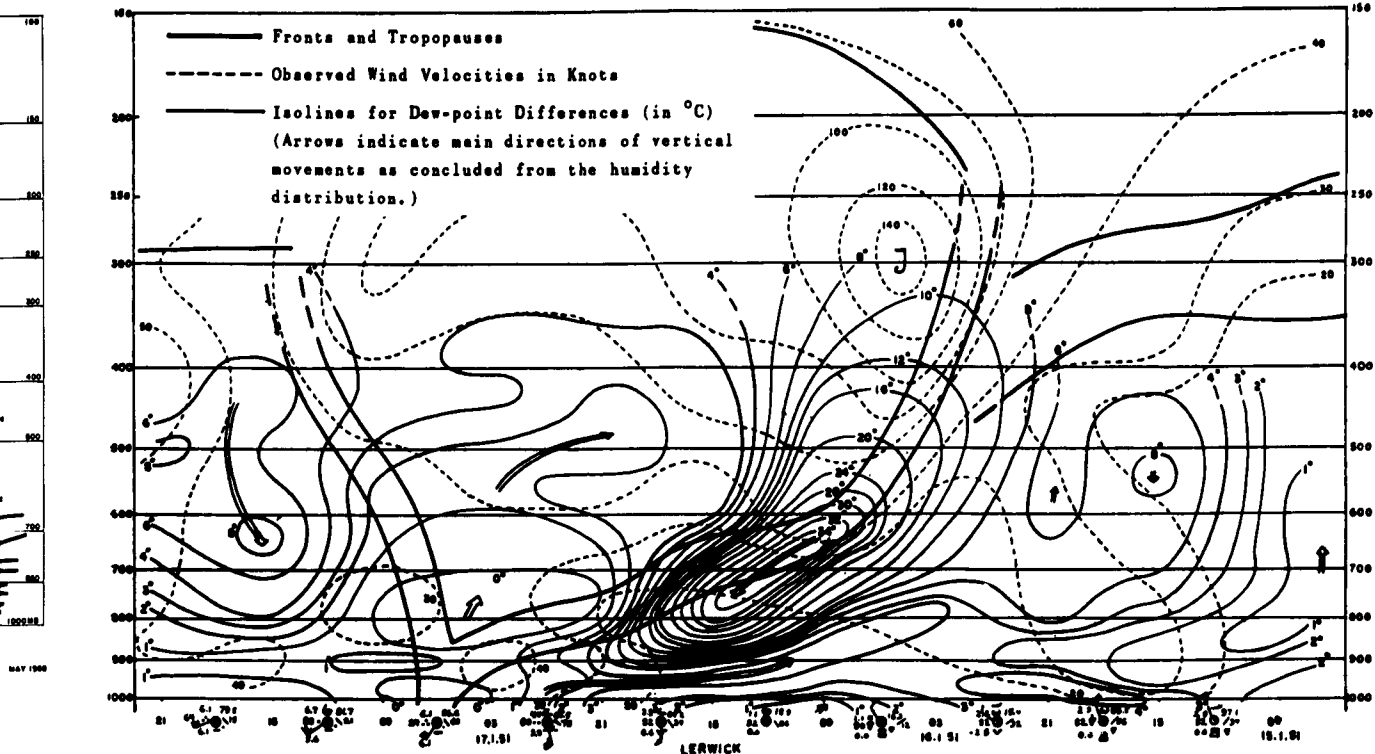


(c) Isopleths of Temperature Dew-point Difference for Lerwick.

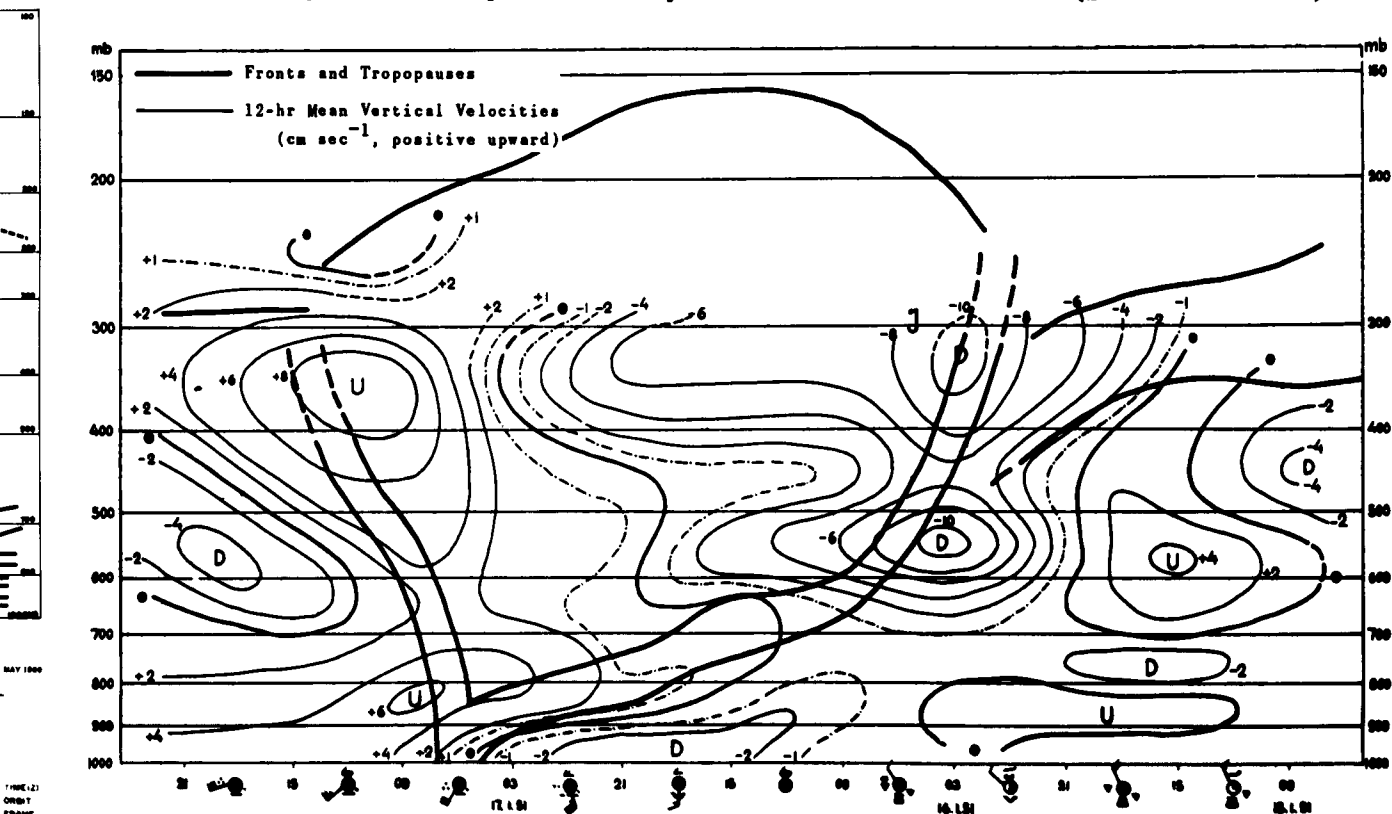


(d) Isopleths of Vertical Velocity (in  $\text{cm sec}^{-1}$ ) Surface Reports Added.

FIG. 32 COMPARISON OF TIME SECTIONS AT OSV PAPA 18-24 MAY 1960 (Left Panels) WITH TIME SECTIONS AT LERWICK (Shetland Islands) 15-17 JANUARY 1951 (After Vuorela, 1953) (Right Panels)



(c) Isopleths of Temperature Dew-point Difference for Lerwick (Shetland Islands).



(d) Isopleths of Vertical Velocity (in  $\text{cm sec}^{-1}$ ) for Lerwick (Shetland Islands).  
Surface Reports Added.

It is immediately evident that in all important and significant details the two cases are quite similar. The following is observed in both cases:

- (1) A general subsiding motion occurs on both sides of the upper tropospheric portion of the warm front.
- (2) There is a coincidence of the central part of the warm air tropopause with a zone of generally ascending motion in the upper air.
- (3) There is a primary association of ascending motion with, and in the vicinity of, the cold front.
- (4) Overcast sky and precipitation accompany rising motion, and clear sky or little cloudiness is associated with descending motion. In the cold air immediately ahead of the warm frontal surface and in the warm air immediately ahead of the cold front, the vertical motion has the same sign through a very deep layer up to 300 mb.
- (5) The heaviest frontal precipitation is reported just below a column of ascending air which extends without interruption from the earth's surface to the upper atmosphere.
- (6) Reports of towering cumuli and showers are in good agreement with the rising motion computed.

In both cases most of the surface observers' reports of cloud types and precipitation agree very well with the distribution of moist and dry regions, as well as with positive and negative vertical velocities computed in the manner outlined by Vuorela (1957).

Whether or not the satellite cloud pictures would have been comparable in Vuorela's case, had they been available, is, of course, not known. This facet of the problem requires further investigation of similar synoptic situations for which satellite pictures are available. Studies in this regard are now underway.



Additional evidence that the distribution of moisture through the well developed trough, in the Pacific case, is typical of troughs with frontal activity is supplied by Newton (see Fig. 33). His illustration shows the deep layer of moisture present ahead of the cold front, and marked drying within the front itself, followed by increasing humidities through a deep layer in the post-frontal area. This drying immediately adjacent to and in the front itself has also been noted by Elliott, 1958.

If this distribution of moisture is translated into cloud forms it closely fits a model of typical cloud structure across a cold front presented by Sawyer, 1955. Interestingly enough, four out of the seven cold-front cases on which his model is postulated, occurred during the existence of blocking conditions, but he presents one synoptic date as typical of the model (see Fig. 34). In his illustration, dense cloudiness is observed within the frontal zone, but the vertical development of these clouds is suppressed at about the 600-mb level. This coincides fairly closely with the strong drying zone and downwind vertical velocities found on the OSV Papa time section between 0000 GMT, 18 May and 0000 GMT, 19 May. In his illustration, the post-frontal area, where the moisture again extends to a deep layer, is occupied by stratocumulus and towering cumulus; in this Pacific case, the towering cumulus clouds were not observed until the frontal surface aloft reached the 500-mb level and the post-frontal area on satellite photographs contains small cellular clouds.

The distribution of clouds through a typical warm front as seen by Sawyer is also evident on the Pacific case time-sections. Note that in his example the majority of clouds of great vertical extent, in general, lie behind the warm front. In the Pacific case the low humidities occupy a broad area through the warm front. Increased moisture and positive vertical velocities associated with vertically well developed clouds are not seen until some distance behind the front. This discrepancy must be considered in proper perspective, since Sawyer's cross section (Fig. 34) is based on a space scale, and our cross sections [Figs. 31(c) and 31(d)] are based on a time scale (with the translation of the system over OSV Papa varying somewhat from day to day).

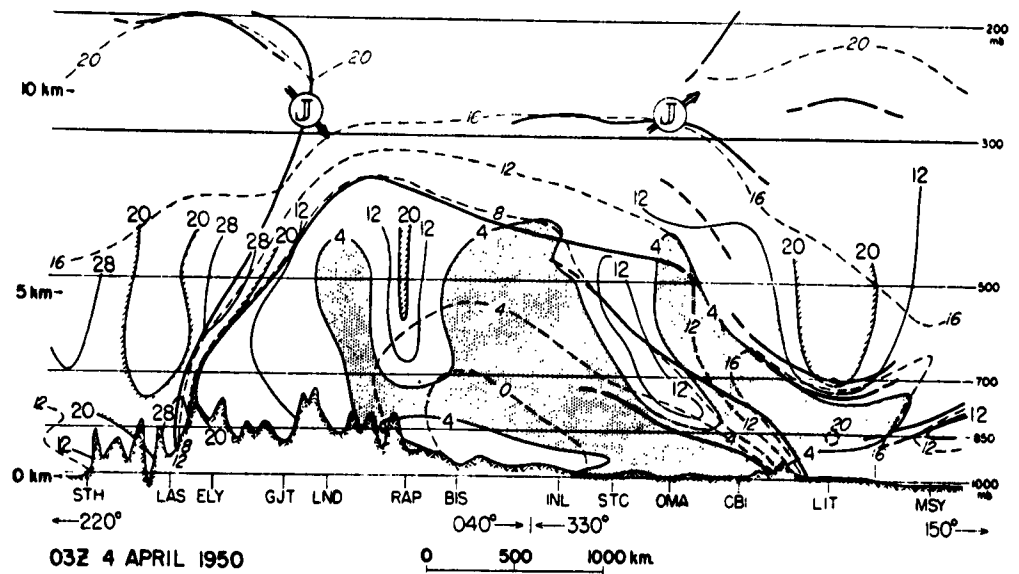
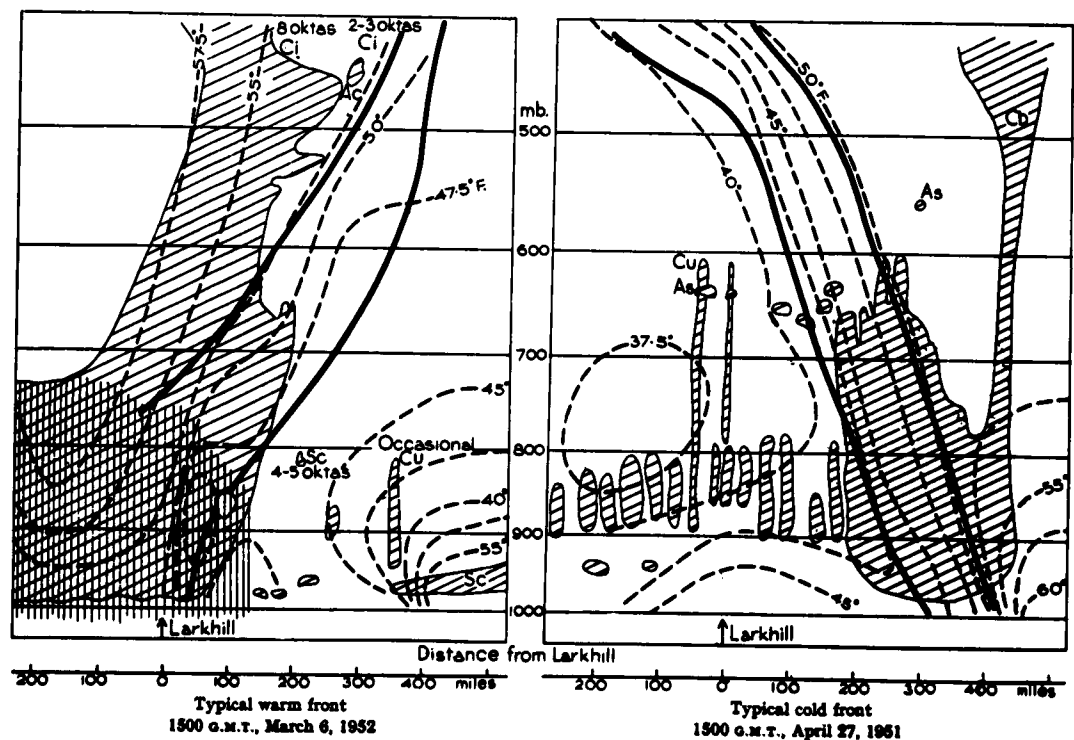


FIG. 33 DISTRIBUTION OF SELECTED ATMOSPHERIC PARAMETERS THROUGH A TROUGH (After Newton, 1959). SOLID LINES, DEW-POINT DEPRESSION (Deg C stippled less than 4°C); DASHED LINES, WET-BULB POTENTIAL TEMPERATURE (Deg C)



--- Saturation Wet Bulb Potential Temperature — Edge of Frontal Zone [Cloud] [Rain]

FIG. 34 TYPICAL CLOUD DISTRIBUTION THROUGH FRONTS (After Sawyer, 1955)

#### IV SUMMARY AND CONCLUSION

During this seven-day period we have seen in most of the Pacific, through the wide-angle camera of TIROS I, the evolution of cloud systems that existed during two distinct pressure regimes. During this time, the sequence of events proceeded from a moderate zonal index (with vortex development) in the first part of the period, to a decidedly low index (strongly meridional flow with a blocking anti-cyclone in the high latitudes) in the second part of the period, with a return to westerly flow in the middle latitude on the last date in the period.

There is a distinct large-scale cloud patterning associated with the changing synoptic situation and, most specifically, with the vortices and fronts as they appear in the various stages of the evolving system. The cloud regime, accompanying the development of the wave system from the 18th to the 21st of May in the central Pacific, closely parallels the theoretical cloud models postulated by Bergeron (1951) and Bjerknes and Solberg (1922), particularly the former. The nephanalysis most definitely supports the cloud models presented by Boucher and Newcomb (1962) which were drawn from a number of satellite views of vortices.

In brief, as a wave develops, the cloud regime changes from a small crown of clouds at the top of an open wave to an ever-expanding prefrontal cloud shield which takes on a spiral form as the wave becomes occluded. The prefrontal cloud shield is dense and opaque on the photographs, with the post-frontal area comparatively clear and occupied by small cellular cloud elements. Degree of cloud coverage in the post-frontal area is governed by the thermal state of the cold air behind the front. The area off the west coast of North America on the 20th and 21st shows how striking the change from prefrontal to post-frontal cloud characteristics can be. In this case with a short trajectory from Alaska, the temperature difference between the cold air and underlying warm water is quite marked, and the amount of cloud is more sparse than in the post-frontal areas of the vortex which develops in the central Pacific. Here the trajectory

over water is lengthy, and the water-air contrast not as great, culminating in greater cloud cover.

In the first half of the period studied the jet stream lies nearly overhead the intersection of the polar frontal surface with the 500-mb level, as has been pointed out previously in the literature. With respect to the surface front the jet-stream centrum is displaced north of the developing-wave stage of a cyclone. In later stages the developing wave moves under the jet-stream centrum and, finally, in the occlusion stage the jet-stream centrum crosses the occlusion near, or slightly north of, the point of occlusion.

Since the frontal stages are fairly well delineated in the cloud pictures, the location of the jet stream in the area of vortices involving fronts is fairly readily established from existing front-jet-stream models. However, there are areas away from vortices where the jet stream is considerably displaced from the surface front and its associated cloudiness and may lie over a totally different cloud field from that of a front. In this event the frontal cloud fields yield less exact clues to location of the jet stream aloft. In other words, there is no direct duplication of the entire jet-stream configuration by a unique cloud type or configuration as seen from the satellite. The jet stream may pass over apparently clear as well as cloudy areas, and the total cloud distribution over a wide area must be considered in jet-stream analysis.

In regard to the cloud distribution over a wide area, Bergeron has presented a schematic model of the relation of clouds, fronts, and jet streams within a wave system. His assessment of the cloud distribution is strongly supported in the first part of this case history. In fact, the mosaic of the 20th of May is almost classical in terms of his model. Bergeron's model of weather regions and the photo-mosaic of the cloud cover on the 20th of May are shown in Fig. 35. Essentially, this model contains eight weather regions related to the principal fronts and air masses. Petterson (1956) gives a description of these weather regions as follows:

"Region I is the cloudless (or almost cloudless) region normally found in the eastern and southeastern part of the subtropical cells of high pressure, where subsidence normally is present. Along subtropical west coasts, where there is upwelling of cold water, fog, or stratus may be present under the dry air.

"Region II consists of more or less undisturbed tropical air moving toward the northeast. As the cooling progresses, stratus, stratocumulus, and (sometimes) fog develop.

"Region III is occupied by tropical air which has moved far out of its source region and been cooled sufficiently to produce low stratus (or fog) and drizzle. In the northern part of the warm sector general convergence and upward motion are usually present, and the drizzle may be mixed with rain.

"Regions IV and V are characterized by extensive systems of nimbostratus (IV) and altostratus (V) resulting from large-scale upglide motion associated with frontal zones. Such clouds are often found also in the rear of cyclones where they are maintained by low-level convergence in the trough of low pressure.

"Region VI is characterized by subsidence in the polar (or arctic) air masses, mainly in the anti-cyclonic circulation patterns at intermediate levels.

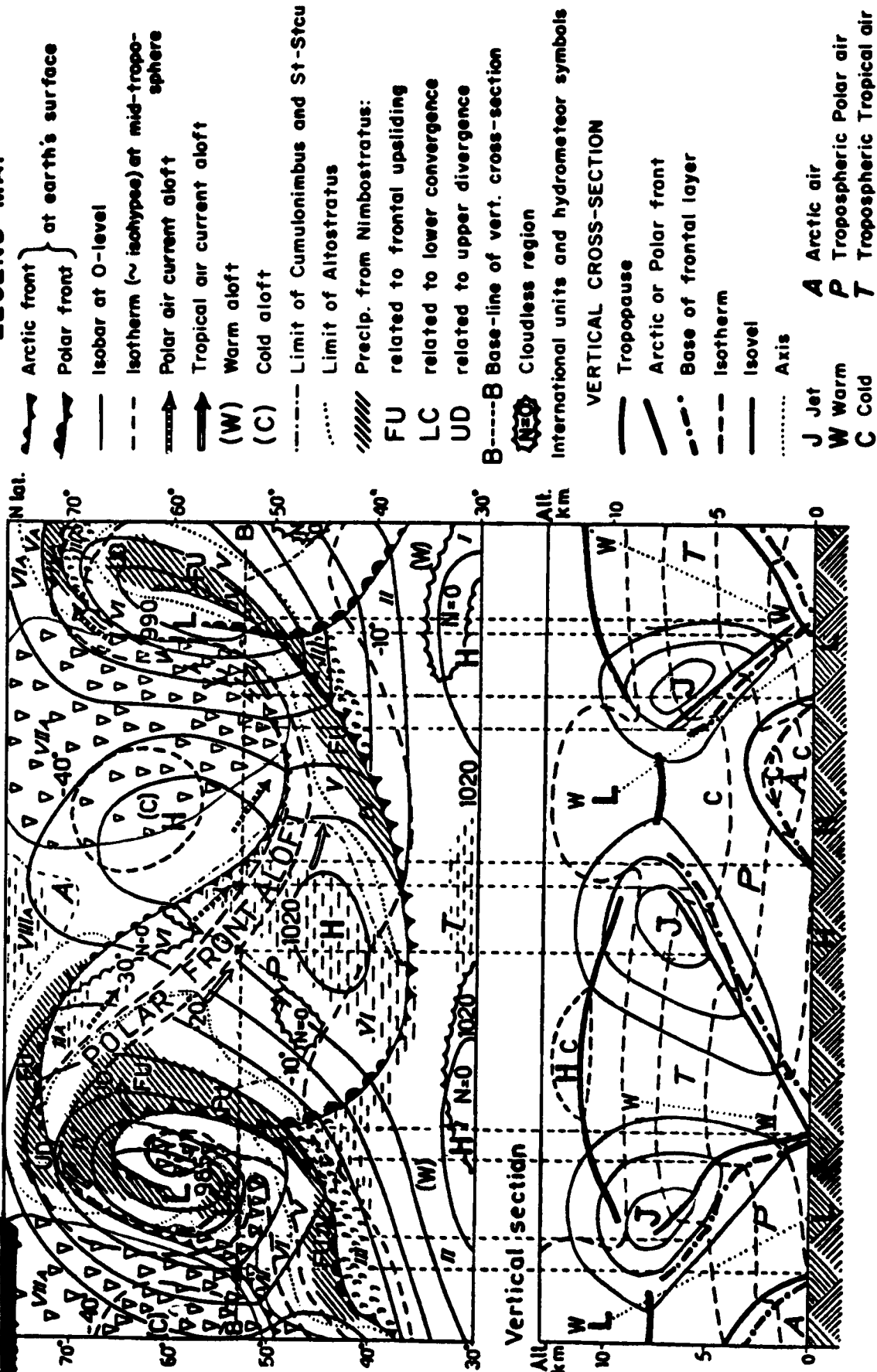
"Region VII is occupied by the unstable (usually cyclonic) branch of the polar and arctic air that streams southward between the sea-level cyclone and the upper cold trough. Convective clouds, showers, and squalls are typical.

"Region VIII is characterized by stratocumulus and stratus which form in the relatively calm parts of polar anti-cyclones. During the cold season fogs are quite frequent when such anti-cyclones settle over land."

# Weather Regions related to Main Fronts and Air Masses.

- I. Cloudless in Tropical air (T)
- II. Stcu - St - fog > > >
- III. Drizzle (or rain) > > >
- IV. Nimbostratus in Polar air (P)

- V. Altostratus in Polar air
- VI. Subsidence > > >
- VII. Showers > > >
- VIII. Stcu - St - fog > > >

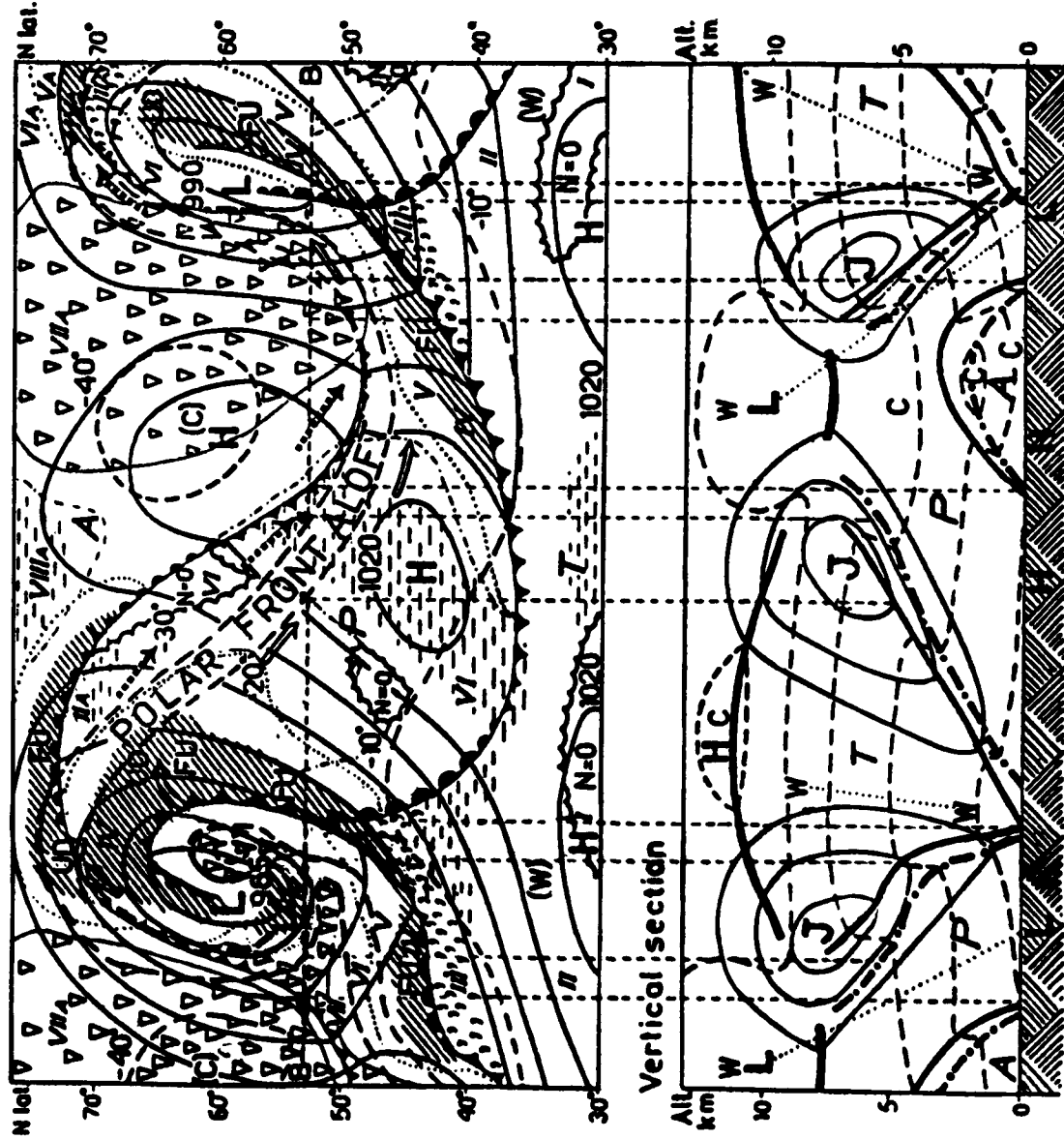


# Weather Regions related to Main Fronts and Air Masses.



- I. Cloudless in Tropical air (T)
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- V. Altostratus in Polar air
- VI. Subsidence > > >
- VII. Showers > > >
- VIII. Stcu - St - fog > > >



## LEGEND MAP

- Arctic front } at earth's surface
  - Polar front }
  - Isobar at O-level
  - Isotherm (~ isohypse) at mid-troposphere
  - Polar air current aloft
  - Tropical air current aloft
  - Warm aloft (W)
  - Cold aloft (C)
  - Limit of Cumulonimbus and St-Stcu
  - Limit of Altostratus
  - Precip. from Nimbostratus
  - FU related to frontal upsliding
  - LC related to lower convergence
  - UD related to upper divergence
  - B-----B Base-line of vert. cross-section
  - (NEO) Cloudless region
- International units and hydrometeor symbols
- ### VERTICAL CROSS-SECTION
- Tropopause
  - Arctic or Polar front
  - Base of frontal layer
  - Isotherm
  - Isovel
  - Axis
- J Jet
  - W Warm
  - C Cold
  - A Arctic air
  - P Tropospheric Polar air
  - T Tropospheric Tropical air

Base-line of vert. cross-section

- NEO Cloudless region
- International units and hydrometeor symbols
- VERTICAL CROSS-SECTION
- Tropopause
  - Arctic or Polar front
  - Base of frontal layer
  - Isotherm
  - Isovel
  - Axis
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- A Arctic air  
P Tropospheric Polar air  
T Tropospheric Tropical air

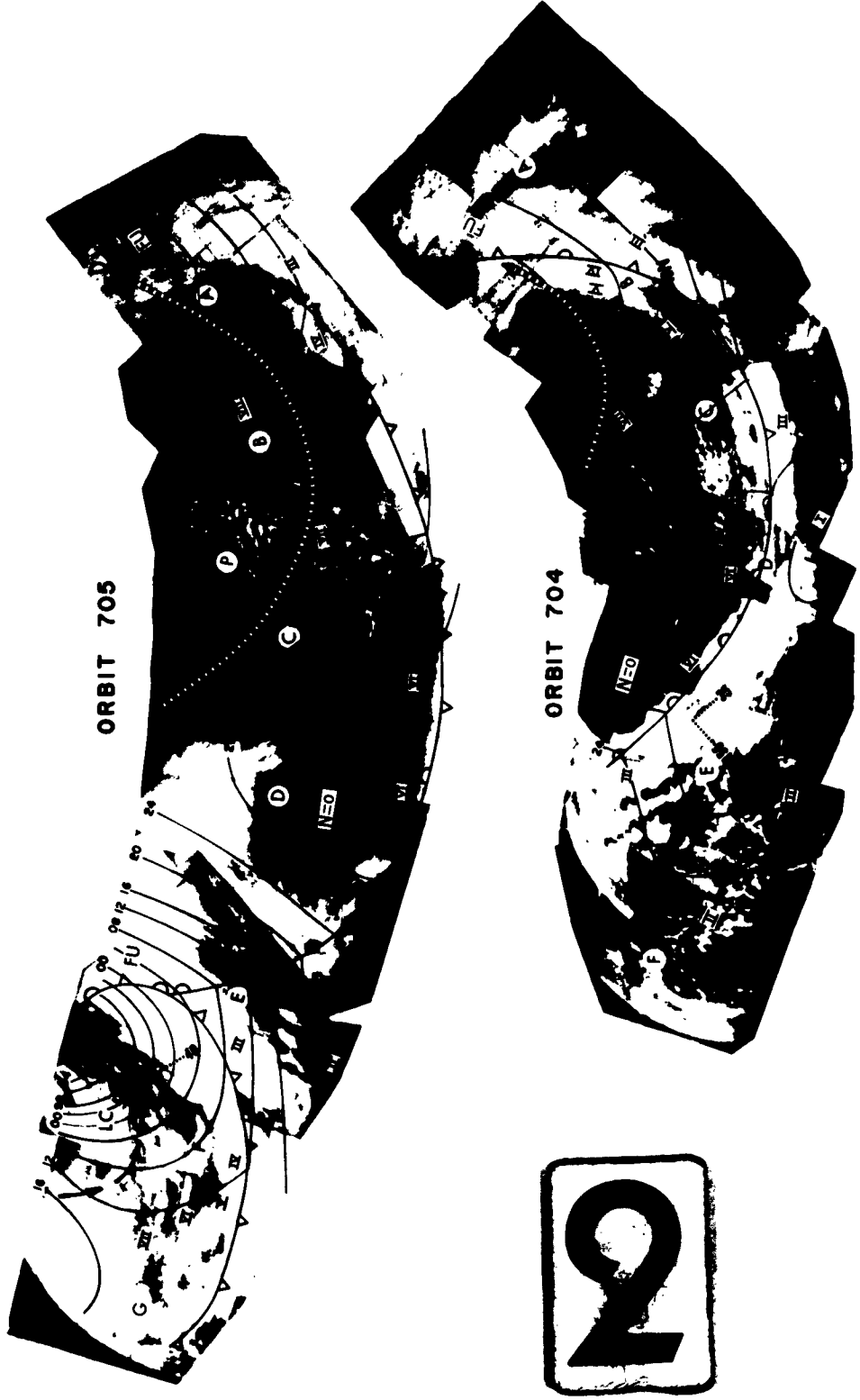
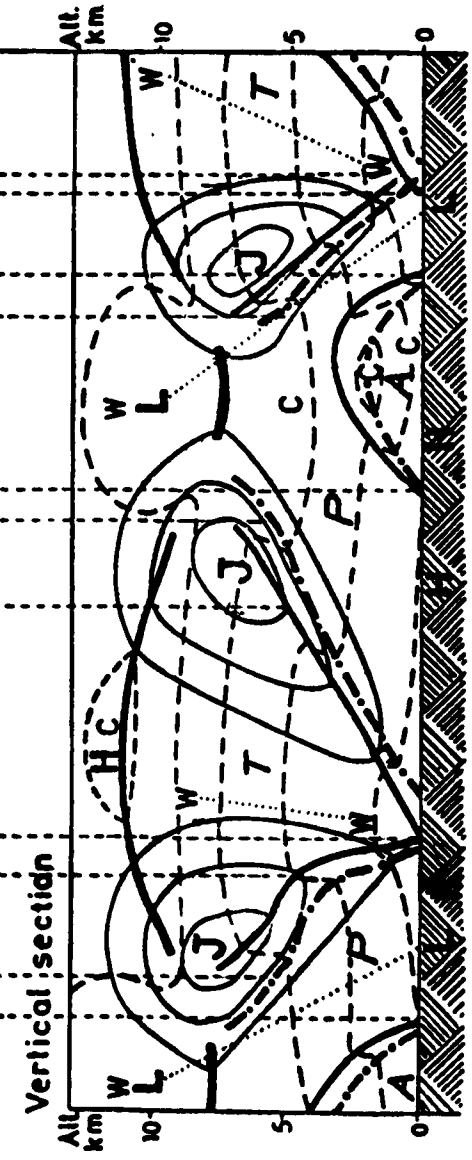


FIG. 35 COMPARISON OF CLOUD DISTRIBUTION FOR 20 MAY 1960 WITH THE BERGERON (1951) MODEL. ROMAN NUMERALS ON PHOTOGRAPHS CORRESPOND TO THOSE IN THE MODEL



The satellite photographs for the first four days during which zonal flow predominated provides confirmation of the concept of the distribution of clouds with the polar-front, as exemplified by the cloud distributions in Bergeron's model.

In the last days of the period, when blocking conditions prevailed, the latitude limitation of TIROS I prevented the observance of the cloud cover in the vicinity of the actual blocking anti-cyclone in high latitudes. Photographs are available, however, which show the cloud changes in the upstream and downstream low-pressure areas that accompany the formation of this block.

During the development of the cold cyclone downstream of the blocking ridge, the cutting off of the cold air supply seems to be marked in the satellite photographs by an extension of an amorphous cloud sheet around the northern perimeter of the vortex. The interior of the cut-off cold cyclone remains rather free of clouds during the development. While there is some evidence that the major cloud systems spiral into these frontless storms, this characteristic is much more ill-defined than in frontal cyclones.

In the initial stages of the downstream low-pressure area formation, there was the appearance of a widespread area of clearing along the northern and western sectors of the cyclonic circulation. This clear area filled with clouds as the cyclone developed and the next frontal system moved in from the west. The maximum-speed region of the jet stream was located in this clear area.

The confluence of the returning warm air around the north side of the vortex and the warm, moist air approaching from the west result in a reformation of clouds in the heretofore clear area after the maximum isotach area of the jet stream moves out of the region, and no extreme subsidence is present. Concomitant with this occurrence strong westerlies are established on the south side of the blocking high-pressure system.

Clouds in the blocking anti-cyclone had the fibrous, broken, and streaky appearance characteristic of middle and high clouds, with the

orientation roughly parallel to the wind flow. The center of the ridge was marked by an area of distinct clearing.

Throughout the period, regardless of the index changes in the middle and high latitudes, the cloud patterns in the subtropical regions were rather persistent when considered on a synoptic scale. In general, the centers of the subtropical anti-cyclones appear free of cloud cover. The cloud fields to the south of these cells are usually arranged in broad bands in the trade-wind zone, reflecting the tendency for clouds to align along asymptotes of streamline convergence. Judging by the varied states of the cloud fields, the complexity of these streamline fields is probably much greater than commonly appreciated.

The extensive cloud bands in the lower latitudes indicate that the effects of the penetrations of cold air from the north are quite long-lasting--even after the means to detect fronts on the conventional basis have been lost.

In Sec. III of this report it was observed that a high degree of moisture through a deep layer is carried ahead of the cold fronts, with pronounced subsidence and drying within the front itself above about the 600-mb level. The post-frontal area is characterized by a moderate degree of moisture in a deep layer, coupled with marked upward velocities. This translates into a satellite photograph of small cellular clouds. Warm fronts show marked subsidence in and ahead of the frontal surface, with most of the moisture lying on the warm side of the frontal surface.

A comparison with other studies indicated that the distribution of moisture and vertical velocities were quite similar, leading to the conclusion that these distributions are perhaps typical of deep troughs with fronts and strong ridge conditions. Satellite photographs taken from additional cases in the TIROS catalogue during similar synoptic conditions will show if the pattern and type changes in cloud cover are also comparable.

Within this case history there were certain relationships observed that will aid in the synoptic interpretation of satellite photographs. Some of these have been embodied in forecasting rules in the past. The more outstanding of these relationships are as follows:

- (1) Where the jet stream is parallel to the cold front, the cloudiness on the cold side of the front usually lies somewhat south of the jet stream isotach system--the exact displacement of cloud to jet-stream core varies considerably with the tilt of the isotach system. Where the jet stream is normal to the cold front, direct association of cloud cover to jet-stream orientation is often not apparent.
- (2) Jet streams on the east side of a long wave ridge are most apt to lie in clear air. They are usually well organized, with strong horizontal and vertical shear through the front, and pronounced temperature gradients between air masses in the upper levels. These conditions will prevail along the jet stream to the area of the high-level cloud shield downstream, at which point the jet stream and its baroclinic zone usually diminishes.
- (3) When the isotach maximum passes over a high-pressure ridge the cloud system--particularly the cirroform clouds--will be elongated along this maximum and lie on the immediate warm side of the jet stream. Decay of these cloud systems usually occurs on the warm side of the jet-stream exit region.
- (4) The organized state of the jet stream will be weakest over the isentropic moist tongue to the east of a developing vortex, due to weakening of the temperature gradient in the upper levels. This is not to imply that strong winds will disappear, but rather that the horizontal and vertical shear gradients will be lessened.
- (5) In general, the large, dense cloud shields associated with vortices in the middle latitudes are oriented along the axis of predominant wind-flow in the lower and middle levels. Cloud streets in post-frontal regions are apt to lie at an angle or even perpendicular to the wind flow in these levels.

- (6) As a rule, in a trough behind an occluding cyclone, the maximum-speed portion of the isotach field lies over clear air or over scattered to broken low-level cloud areas, depending upon the stage of cyclone development.
- (7) Both katabatic and anabatic frontal cloud formations are observed, particularly with cold fronts. When the cloud mass lies ahead of the cold front with a sharp edge to the cloud system at the frontal boundary (rapid clearing), then the winds aloft are usually normal to the front. When the cloud system lags behind the front, the upper winds are apt to be parallel to the front, at least as far as the clouds extend. Obviously, in an area of sparse data, the precise frontal location is difficult to determine, but if in the analyses one of these conditions is specified, then for reasons of consistency the direction of the upper wind flow appropriate to this condition should be forecast.
- (8) During situations of strong vortex development, when the axis of the upper trough is nearly over the surface low-pressure center, the overrunning prefrontal cloudiness--particularly the cirrus shield--will rarely proceed beyond the upper-level ridge line downstream.
- (9) In frontless vortices (cold cut-off cyclones) cloudiness is prevalent around the periphery of the vortex.
- (10) Post-frontal regions, in which fresh, cold air is involved, are observed in satellite photographs as areas covered by small, cellular type clouds, often in streets but not necessarily so.
- (11) In the eastern Pacific the flow of cold air from a high-pressure cell in the middle latitude into the subtropics may be identified by the appearance of a broad band of clouds on the southeastern side of the high extending east-west. On occasion the extent of this band can be followed westward to the frontal system lying to the west of the anti-cyclone.

In general, broad-scale changes in clouds occur only through a major development in the synoptic situation. Cloud systems were recognizable for as much as four days, particularly in the middle latitudes. Small-scale changes in cloud cover, due to localized processes and influences, were not considered in this study.

Jet-stream analysis is aided by the satellite cloud pictures as far as location is concerned. They do not aid in establishing the strength of the wind field, as yet. Perhaps this can be determined in future studies. In any event, satellite photographs contribute much in the way of analytical evidence in areas where conventional observations are sparse. With additional experience, satellite photographs will take their place alongside the conventional tools of meteorology.

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